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# THE USE OF COAL AND MODIFIED COALS AS ADSORBENTS FOR REMOVING ORGANIC CONTAMINANTS FROM WASTE WATERS

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Bureau of Mines
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by

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Final Report - Feb. 1, 1963-Jan. 31, 1964.

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## ABSTRACT

Batch tests of coals and coal-derived materials were made to determine their effectiveness in removing organic contaminants (COD and ABS) from the final effluent of secondary-treated waste waters. The adsorptive capacity of flyashes, coals, including at least one sample of each rank found in this country, pretreated coals, and miscellaneous materials including commercial chars and coke was determined and compared with that of granular activated carbon. The coals, though not as effective as activated carbon, possess an economic advantage--they are relatively inexpensive and after use in waste-water treatment can still be burned as fuel without any loss of fuel value. A hvcb coal was found to be one of the best, having about one-fourth the capacity of activated carbon for COD, adsorbing about 4 percent of its weight before it became saturated. Several coals were found to contain constituents that added to the COD content of the treated water. Thus knowledge of the performance of the coal is necessary to insure selection of a proper coal as adsorbent.

Some of the flyashes tested were quite effective, removing as much as 66 percent of the COD and 76 percent of the ABS present. The effectiveness of the flyashes improves with increasing carbon content. Coals pretreated by mild oxidation were ineffective as adsorbents.

## INTRODUCTION

As population and industry expand, the water needs of our country are becoming critical. To alleviate the water shortage, multiple re-use of water has become a necessity in many highly industrialized areas. As a result, pollution of our rivers and streams is a growing problem despite the increase in the number of waste treatment plants in use.

Today's best conventional waste treatment processes remove only about 80 percent of the organic pollutants present, while less efficient or primary treatment plants remove only 25-35 percent. The residual contaminants which are either partly or wholly resistant to treatment are returned to the rivers and streams; further downstream this water containing these same contaminants is pumped into a municipal or industrial water plant and the cycle is repeated. The physiological effects of these refractory contaminants have not been fully evaluated, but in addition to contributing to the aesthetic effects of unpleasant tastes and odors, the dissolved materials can cause corrosion, scale and other such economic burdens.

Some method of treatment to complement conventional waste treatment is necessary to reduce water pollution. One of the more favorable of currently known methods for tertiary treatment of sewage effluents being investigated is the use of adsorbents. Activated carbon, a widely used adsorbent, has proven to be highly effective for removal of the residual organic materials in sewage effluents.[1/] However, its initial cost is relatively high and the cost of regenerating it is appreciable.

---

1/ Sukenik, V. A., and R. S. Joyce. "Removal of Organic Compounds from Secondary Sewage Effluent Using Granular Regenerable Activated Carbon", presented before the Division of Water and Waste Chemistry, American Chemical Society, Cincinnati, Ohio, January 1963.

The object of this study was to evaluate the various ranks of coal and coal-derived materials as adsorbents for the refractory organic contaminants in effluents from secondary sewage treatment plants. The removal of organic material was of major interest although ABS removals were also investigated.

In addition to their low initial cost, coals offer the advantage of not requiring regeneration because they can be burned as fuel after use as adsorbents. Burning of the spent adsorbent would also solve the problem of ultimate disposal of the wastes that have been removed, a problem as yet unresolved with many tertiary treatment processes.

## EXPERIMENTAL PROCEDURE

### Description of Equipment

Figure 1 is a photograph of the testing equipment used in this study. The test flasks were contained in a stainless steel water bath 5 feet long, 2 feet wide, and 1 foot high. The temperature of the bath water was controlled at 22° C $\pm$ 0.5° by a thermoregulator. Plant circulating water was used in the cooling coils and heat was provided by a flexible 1,000-watt heater. A circulating pump with a delivery capacity of 2.0 gal/min provided uniform temperatures throughout the bath.

The test vessels were 4-liter side-arm Erlenmeyer flasks held in position by clamps secured to the overhead framework of the bath. The flasks were fitted with teflon-lined brass caps through which the stirring rod shafts pass. The stirrers were made of stainless steel with teflon bearings, and were equipped with special fins to prevent the formation of the vortex experienced with conventional stirrers. Figure 2 is a photograph of a conventional stirrer illustrating the vortex, while

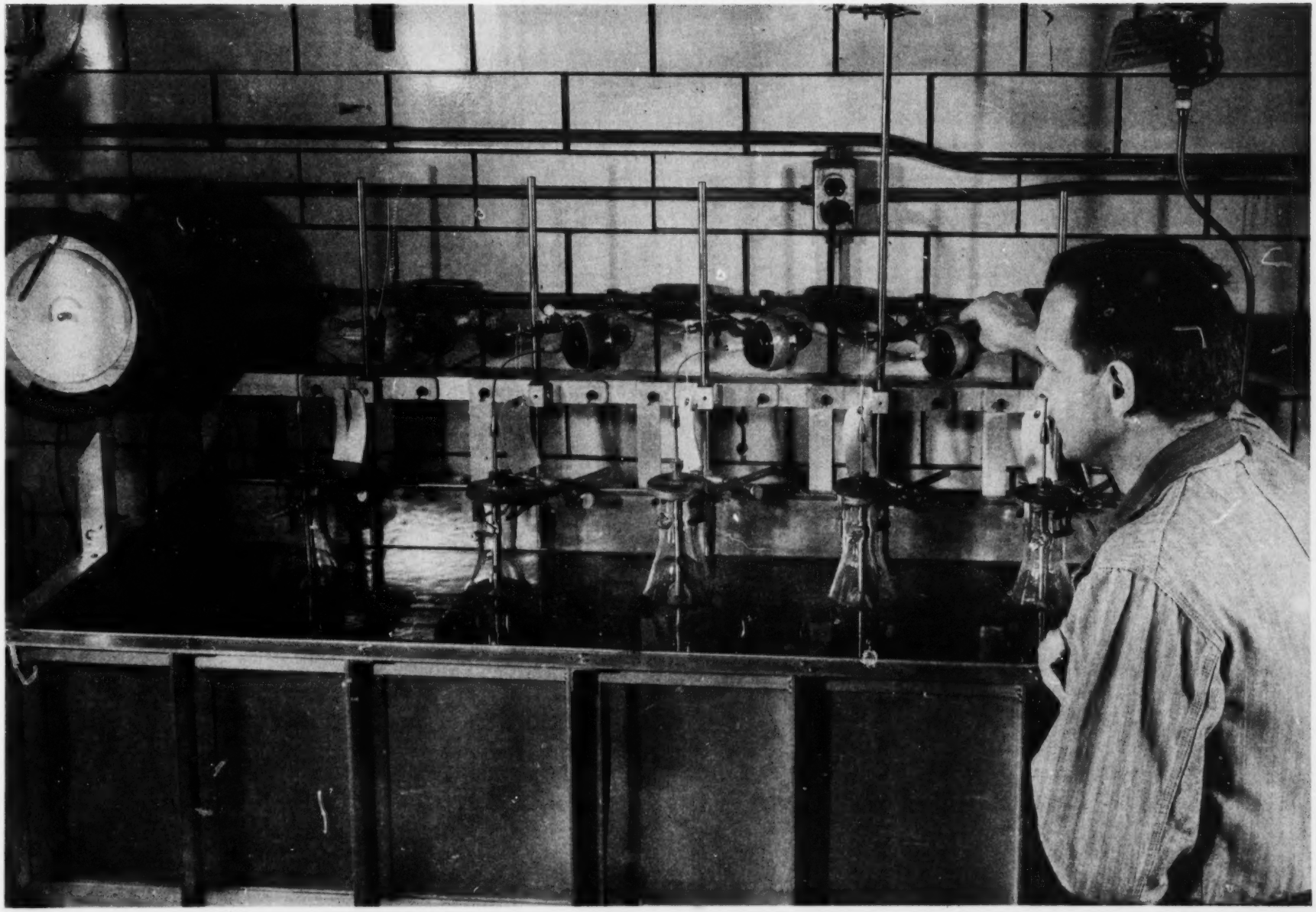

Figure 1. View of Equipment Used in Wastewater Study.

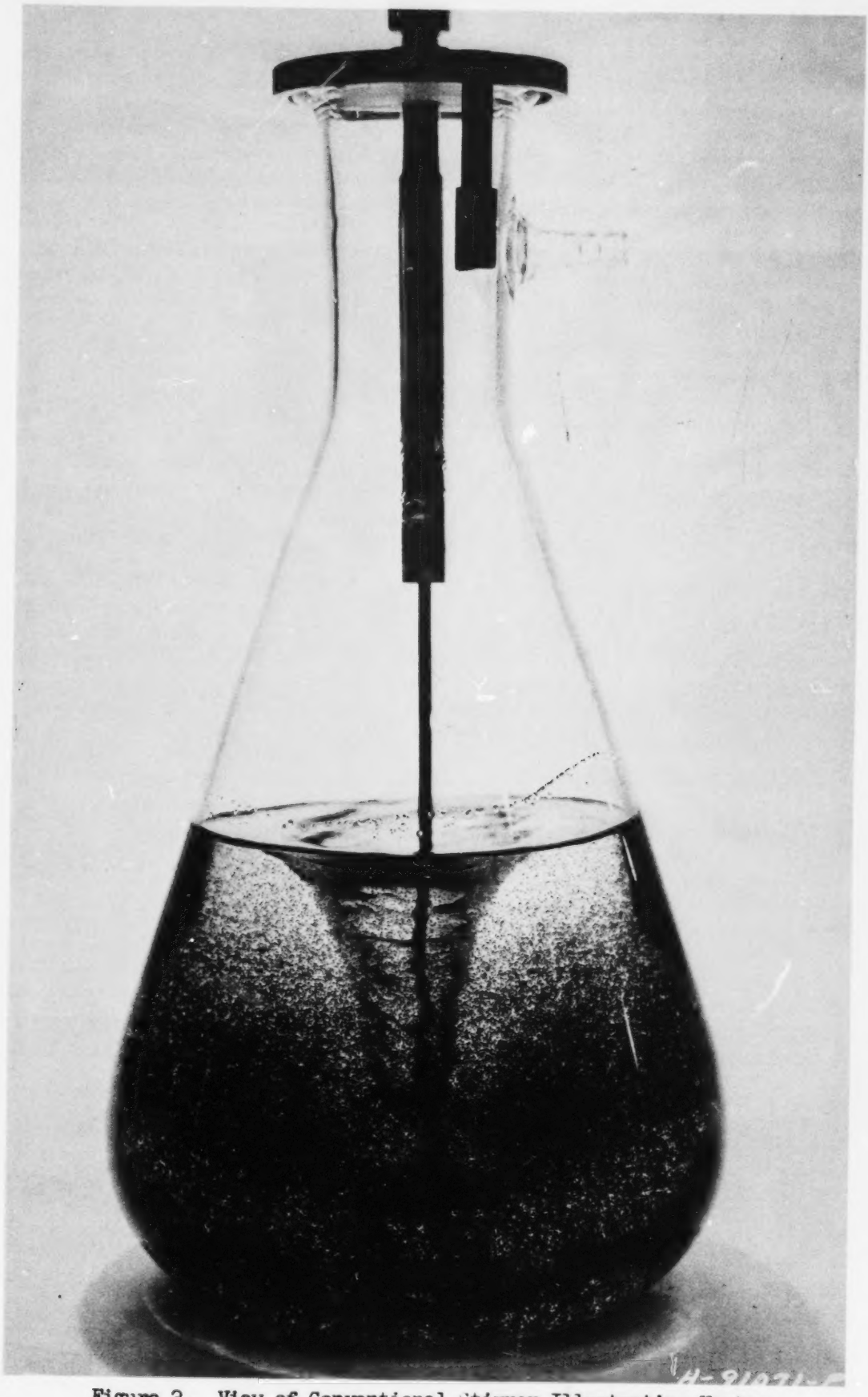

Figure 2. View of Conventional Stirrer Illustrating Vortex.

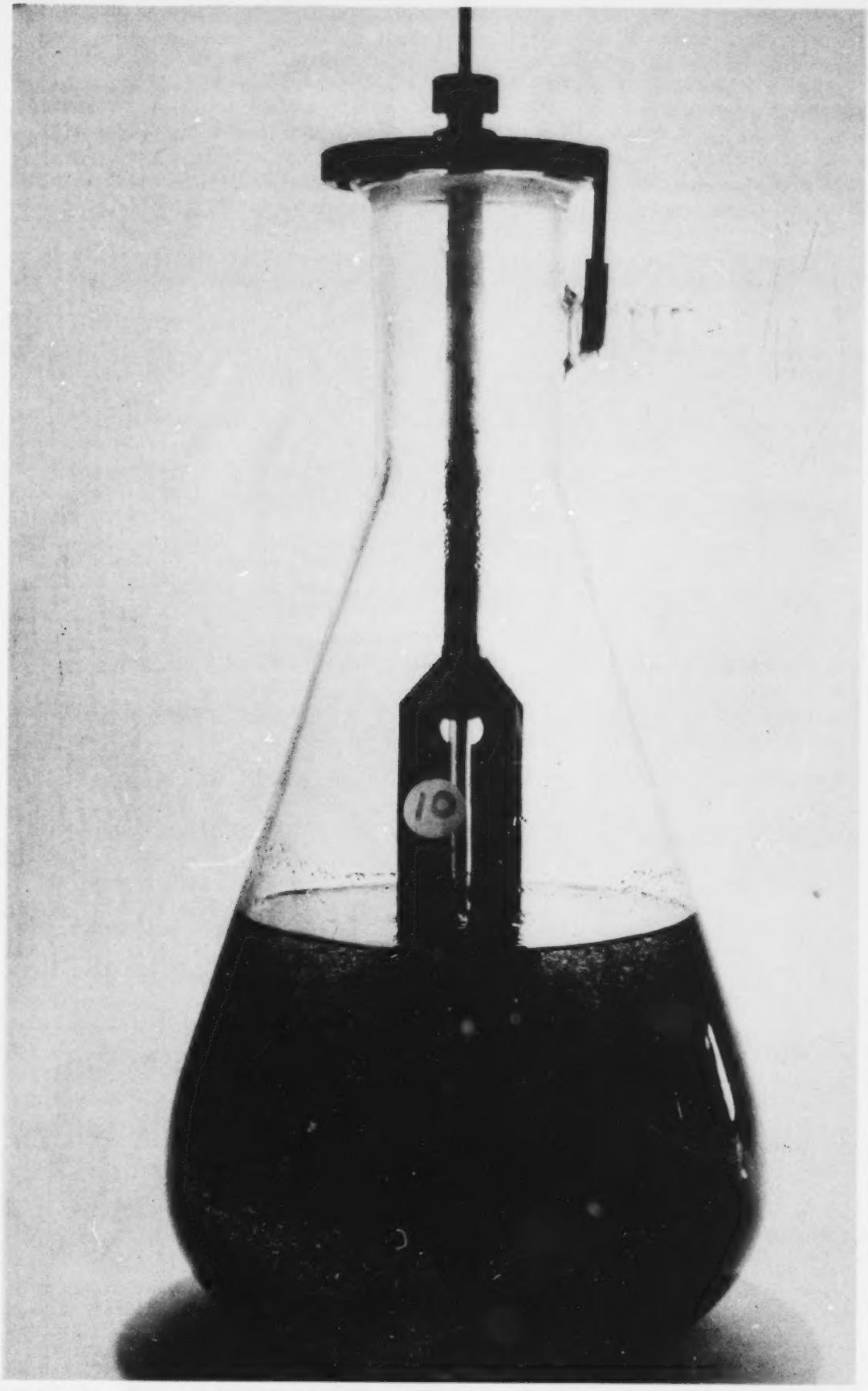


Figure 3. View of Bureau of Mines Designed Stirrer Showing Absence of Vortex.

the absence of a vortex is clearly shown in figure 3 with our stirrer. The stirrers in the two photographs were being driven at the same speed, and in each case the same particle size and weight of coal were used. The elimination of the vortex eliminates foaming to a great degree, yet provides good solids movement and solids suspension. Elimination of the excessive agitation accompanying the vortex also tends to decrease particle attrition and aeration of the liquid being stirred.

The stirrers were driven by 1/100 HP motors and operated at a speed of 1,200-1,500 rpm. The motors were mounted at right angles to the stirrers and were connected with flexible speedometer cables to eliminate binding which was experienced when solid connectors were used.

## Test Procedure

### Collection and Preparation of Adsorbents

Since coals are normally classified according to rank, and are so listed in this study, the A.S.T.M. classification of coals is given in table 1. (Ref. U.S.B.M. "Mineral.Facts and Problems", Bull. 585, 1960, p. 115).

Coal samples were obtained at the mines in whatever condition the particular coal company ordinarily provided the coal for commercial use. Generally the coals as received had been washed or mechanically cleaned and usually sized. Most of the samples were of freshly mined coal although some were undoubtedly taken from stockpiles and may have been somewhat weathered.

The flyashes and commercial chars tested were obtained by request from the companies with which they are identified in the table, and it is assumed that the samples are representative of the usual powerplant operation.

TABLE 1.- A.S.T.M. classification of coals by rank[1, 2/]

(F.C. = fixed carbon; V.M. = volatile matter; Btu = British thermal units)

| Class | Group | Limits of fixed carbon or Btu, mineral-matter-free basis | Requisite physical properties |
|---|---|---|---|
| I. Anthracitic | 1. Meta-anthracite... | Dry F.C., 98 pct or more (dry V.M., 2 pct or less). | |
| | 2. Anthracite..... | Dry F.C., 92 pct or more and less than 98 pct (dry V.M., 8 pct or less and more than 2 pct). | |
| | 3. Semianthracite.... | Dry F.C., 86 pct or more and less than 92 pct (dry V.M., 14 pct or less and more than 8 pct). ..... | Nonagglomerating.[3/] |
| II. Bituminous[4/] | 1. Low-volatile bituminous coal... | Dry F.C., 78 pct or more and less than 86 pct (dry V.M., 22 pct or less and more than 14 pct). | |
| | 2. Medium-volatile bituminous coal... | Dry F.C., 69 pct or more and less than 78 pct (dry V.M., 31 pct or less and more than 22 pct). | |
| | 3. High-volatile A bituminous coal... | Dry F.C., less than 69 pct (dry V.M., more than 31 pct); and moist Btu[5/] 14,000[6/] or more. | |
| | 4. High-volatile B bituminous coal... | Moist Btu,[5/] 13,000 or more and less than 14,000.[6/] | |
| | 5. High-volatile C bituminous coal... | Moist Btu,[5/] 11,000 or more and less than 13,000.[6/] ..... | Either agglomerating or nonweathering.[7/] |

Continued on next page

TABLE 1.- A.S.T.M. classification of coals by rank[1, 2/] cont'd

(F.C. = fixed carbon; V.M. = volatile matter; Btu = British thermal units)

| Class | Group | Limits of fixed carbon or Btu, mineral-matter-free basis | Requisite physical properties |
|---|---|---|---|
| III. Subbituminous | 1. Subbituminous A coal..... | Moist Btu[5/] 11,000 or more and less than 13,000.[6/] ..... | Both weathering and nonagglomerating. |
| | 2. Subbituminous B coal ..... | Moist Btu,[5/] 9,500 or more and less than 11,000.[6/] | |
| | 3. Subbituminous C coal ..... | Moist Btu,[5/] 8,300 or more and less than 9,500.[6/] | |
| IV. Lignitic | 1. Lignite ..... | Moist Btu,[5/] less than 8,300.[6/] ..... | Consolidated. |
| | 2. Brown coal ..... | Ditto ..... | Unconsolidated. |

1/ U.S. Bureau of Mines Mineral Facts and Problems, Bulletin 585, 1960, p. 115.

2/ This classification does not include a few coals that have unusual physical and chemical properties and that come within the limits of fixed carbon or Btu of the high-volatile bituminous and subbituminous ranks. All of these coals either contain less than 48 pct dry, mineral-matter-free fixed carbon or have more than 15,500 moist, mineral-matter-free Btu.

3/ If agglomerating, classify in low-volatile group of the bituminous class.

4/ It is recognized that there may be noncaking varieties in each group of the bituminous class.

5/ Moist Btu refers to coal containing its natural bed moisture but not including visible water on the surface of the coal.

6/ Coals having 69 pct or more fixed carbon on the dry, mineral-matter-free basis shall be classified according to fixed carbon regardless of Btu.

7/ There are three varieties of coal in the high-volatile C bituminous group; namely (1) agglomerating and nonweathering; (2) agglomerating and weathering; (3) nonagglomerating and nonweathering.

Table 2 lists the adsorbents tested according to the assigned test number. All the basic information is given as to the source of the sample; if coal, the rank, seam, mine, etc. The conditions of pretreatment are given for the pretreated coals as well as the rank of coal used. The sources of the flyashes as well as carbon contents are listed. Table 3 lists the proximate and ultimate analyses of the coals tested.

Each of the adsorbents to be tested (excluding flyashes and peat) were ground and sieved to 14-100 mesh size. The 42-60 mesh size was separated for use in the adsorption tests; however, several tests utilized 200-250 mesh particles instead. The selected mesh size adsorbents were washed with de-ionized water until all dust and fines were removed, then dried at 105°C for 24 hours.

## Preparation of Adsorbate

Secondary sewage effluent from either the Pleasant Hills, Pa., or Bethel Park, Pa., treatment plants was used throughout this study. In several instances, when the COD value of the final effluent was low, primary sewage was added to increase the concentration. Both the Pleasant Hills and Bethel Park treatment plants are located in suburban Pittsburgh and provide secondary treatment to essentially domestic sewage. The Pleasant Hills plant employs activated sludge, while the Bethel Park plant is a trickling-filter type operation.

Final effluent samples were biologically stabilized by heating at 180° F for 10 minutes in accordance with recommendations of the Advanced Waste Treatment Research Program. The stabilized sewage was then filtered through No. 5 Whatman filter paper using a Büchner funnel and aspirator, thus providing more uniform samples. Initial particle removal was

TABLE 2.- Identification of adsorbents tested in waste water treatment

| Test No. | Adsorbent material and source |
|---|---|
| 1-A | High volatile B bituminous coal, Ohio No. 6 seam, Nelms No. 1 Mine, Cadiz, Ohio. |
| 1-R | Rejects, same source as 1-A. |
| 2-A | Low volatile bituminous coal, Pocahontas No. 3 seam, Buckeye Mine, Stephenson, W. Va. |
| 2-R | Rejects, same source as 2-A. |
| 3-A | High volatile B bituminous coal, Kentucky No. 11 seam, Grapevine Mine, Madisonville, Ky. |
| 3-R | Rejects, same source as 3-A. |
| 4-A | High volatile anthracite, Kocher, Anthracite Research Center, Schuylkill Haven, Pa. |
| 5-A | Medium volatile anthracite, St. Nicholas, Anthracite Research Center, Schuylkill Haven, Pa. |
| 6-A | Subbituminous C coal, Smith-Rolling seam, Wyodak Mine, Gilette, Wyoming. |
| 7-A | Lignite, Beulah Mine, Beulah, N. Dakota. |
| 8-A | High volatile C bituminous coal, unknown seam, Sundance Mine, Gallup, N. Mexico. |
| 9-A | Subbituminous B coal, Laramie seam, Eagle Mine, Erie, Colorado. |
| 10-A | High volatile C bituminous coal, unknown seam, Pioneer Cannon No. 1 Mine, Florence, Colorado. |
| 10-R | Rejects, same source as 10-A. |
| 11-A | Pretreated high volatile A bituminous coal, Pittsburgh seam, U.S.B.M. Mine, Bruceton, Pa.; pretreated at 30°-450° C in 195 minutes with steam and 1.2 pct $O_2$ at atm pressure. |
| 12-A | Pretreated high volatile A bituminous coal, Pittsburgh seam, U.S.B.M. Mine, Bruceton, Pa.; pretreated from 30°-600° C in 8 hr with steam at atm pressure. |

TABLE 2.- Identification of adsorbents tested in waste water treatment, cont'd

| Test No. | Adsorbent material and source |
|---|---|
| 13-A | Pretreated high volatile A bituminous coal, Pittsburgh seam, U.S.B.M. Mine, Bruceton, Pa.; pretreated from 30°-500° C in 205 minutes with steam and 1.2 pct $O_2$ at atm pressure. |
| 14-A | Pretreated high volatile A bituminous coal, Pittsburgh seam, U.S.B.M. Mine, Bruceton, Pa.; pretreated with steam and 1.0 pct $O_2$ from 100°-430° C in 5 hours at atm pressure. |
| 15-A | Pretreated high volatile A bituminous coal, Pittsburgh seam, U.S.B.M. Mine, Bruceton, Pa.; pretreated at 400°, 425°, and 450° C in a fluidized bed at atm pressure. |
| 16-A | Pretreated high volatile A bituminous coal, Pittsburgh seam, U.S.B.M. Mine, Bruceton, Pa.; pretreated at 1,000° C with $N_2$ at atm pressure. |
| 17-A | Wheeling metallurgical coke. |
| 18-A | Gary metallurgical coke. |
| 19-A | Subbituminous B coal, unknown seam, Elkol Mine, Lincoln County, Wyoming. |
| 20-A | High volatile C bituminous coal, Illinois No. 2 seam, Banner No. 27 Mine, Fulton County, Illinois. |
| 21-A | Mont Char - a special fluidized coal char obtained from Pittsburgh Consolidation Coal Co. |
| 22-A | Disco (treated smokeless coal), Pittsburgh Consolidation Coal Co. |
| 23-A | Activated carbon, Pittsburgh Chemical Co., Type SGL. |
| 24-A | Low volatile bituminous coal, Upper Kittanning (C prime) seam, Korduck Coal Co., Portage, Pa. |
| 25-A | Low volatile bituminous coal, Lower Freeport "D" seam, Pennsylvania Coal and Coke Co., Cambria County, Pa. |
| 26-A | Low volatile bituminous coal, Lower Kittanning "B" seam, Marport Coal Co., Portage, Pa. |

TABLE 2.- Identification of adsorbents tested in waste water treatment, cont'd

| Test No. | Adsorbent material and source |
|---|---|
| 27-A | Coal ashes (cinders) from Bruceton boiler house, Bureau of Mines, Bruceton, Pa. |
| 28-A | Pretreated high volatile A bituminous coal, Pittsburgh seam, U.S.B.M. Mine, Bruceton, Pa.; pretreated with steam at atm pressure from 30° to 775° C in 13 hours. |
| 29-A | Pretreated high volatile A bituminous coal, Pittsburgh seam, U.S.B.M. Mine, Bruceton, Pa.; pretreated with steam containing 1.5 pct $O_2$ at atm pressure for 7 hours from 30°-600° C. |
| 30-A | Pretreated low volatile bituminous coal, Upper Kittanning seam (C prime), pretreated with steam and 3 pct $O_2$ to 470° C at atm pressure for 6 hours. |
| 31-A | Anthracite refuse, Greenwood, from Anthracite Research Center, Schuylkill Haven, Pa. |
| 32-A | High volatile anthracite refuse, same source as sample 4-A. |
| 33-A | Medium volatile anthracite refuse, same source as sample 5-A. |
| 34-A | Flyash from Bruceton boiler house, Bureau of Mines, Bruceton, Pa. Carbon = 35.28 pct. |
| 34-R | Flyash washings, same source as 34-A. |
| 35-A | Flyash, West Penn Power Plant, Mitchell Station, New Eagle, Pa. Carbon = 6.0 pct. |
| 36-A | Pretreated low volatile bituminous coal, Lower Kittanning seam, Marport Mine, Portage, Pa.; pretreated with steam and 1.5 pct $O_2$ at atm pressure to 500° C. |
| 37-A | Pretreated high volatile A bituminous coal, Pittsburgh seam, U.S.B.M. Mine, Bruceton, Pa.; pretreated with steam and 1.5 pct $O_2$ at 300 psi to 435° C. |
| 38-A | Pretreated low volatile bituminous coal, Pocahontas No. 3 seam, Buckeye No. 3 Mine, Stephenson, W. Va.; pretreated with $N_2$ at 300 psi and 425° C. |
| 39-A | Steel mill slag. |
| 40-A | Medium volatile bituminous coal, Sewell seam, Lochgelly Mine, New River Co., Summerlee, Fayette County, W. Va. |

TABLE 2.- Identification of adsorbents tested in waste water treatment, cont'd

| Test No. | Adsorbent material and source |
|---|---|
| 40-R | Refuse from same source as 40-A. |
| 41-A | Semi-anthracite coal, Treverton, Anthracite Research Center, Schuylkill Haven, Pa. |
| 42-A | Flyash from Dayton Power and Light Co., Dayton, Ohio. Carbon = 1.98 pct. |
| 43-A | Flyash from Duquesne Light Co., Floreffe, Pa. Carbon = 6.0 pct. |
| 44-A | Lignite char from Gasifier Run No. 11, received from Lignite Research Lab., U.S.B.M., Grand Forks, N. Dakota. |
| 45-A | Pretreated low volatile bituminous coal, Pocahontas No. 3 seam, Buckeye No. 3 Mine, Stephenson, W. Va.; pretreated with inert at atm pressure and 400° C for 15 minutes. |
| 46-A | Pretreated low volatile bituminous coal, Pocahontas No. 3 seam, Buckeye No. 3 Mine, Stephenson, W. Va.; Pretreated with $CO_2$ and air at 400° C for 15 minutes at atm pressure. |
| 47-A | Pretreated low volatile bituminous coal, Pocahontas No. 3 seam, Buckeye No. 3 Mine, Stephenson, W. Va.; pretreated with air at 425° C for 15 minutes at atm pressure. |
| 48-A | Pretreated low volatile bituminous coal, Pocahontas No. 3 seam, Buckeye No. 3 Mine, Stephenson, W. Va.; pretreated with $N_2$ and air at 425° C for 15 minutes at 300 psi. |
| 49-A | Pretreated low volatile bituminous coal, Pocahontas No. 3 seam, Buckeye No. 3 Mine, Stephenson, W. Va.; pretreated with $CO_2$ and air at 410° C for 15 minutes at 300 psi. |
| 50-A | Flyash from Tennessee Valley Authority, Colbert Steam Plant, Tuscumbia, Ala. Coal used was of ASTM Rank Class II, Group 4, West Kentucky Coal. Carbon - 2.4 pct. |
| 51-A | Pretreated low volatile bituminous coal, Pocahontas No. 3 seam, Buckeye No. 3 Mine, Stephenson, W. Va.; pretreated with air to fluidize at 220° C for 15 minutes at 300 psi. |

TABLE 2.- Identification of adsorbents tested in waste water treatment, cont'd

| Test No. | Adsorbent material and source |
|---|---|
| 52-A | Flyash from West Penn Power Co., Courtney, Washington County, Pa. Flyash sampled from Units #1 and #2 section of the Power Plant. Coal was composed of 60-80 pct Pittsburgh seam Deep Mine and the balance was Redstone and Pittsburgh seam strip coal. Carbon = 6.66 pct. |
| 53-A | Flyash from West Penn Power Company, Courtney, Washington County, Pa. Flyash sampled from Unit 3 section of Power plant. Coal composition was same as 52-A. Carbon = 5.28 pct. |
| 54-A | Flyash from Minnesota Power and Light Co., Clay Boswell S.E. Station, Cohasset, Minn. Coal used was Nelms No. 2 seam from Cadiz, Ohio. Carbon = 20.4 pct. |
| 55-A | Michigan peat moss. |
| 56-A | Flyash, Cincinnati Gas and Electric Co., W.C. Beckjord Sta., New Richmond, Ohio. Sampled from No. 5 unit boiler; used 11 and 12 strip coal from W. Kentucky. Carbon = 2.7 pct. |
| 57-A | Flyash, Public Service and Gas Co., Newark, N.J., Essex Generating Station No. 1 unit. Carbon = 0.9 pct. |
| 58-A | Flyash. T.V.A., Shawnee Steam Plant Unit No. 6, Paducah, Kentucky. Carbon = 4.5 pct. |
| 59-A | Flyash, Pacific Power and Light Co., Dave Johnson Power Plant, Glenrock, Wyoming. Carbon = 0.1 pct. |
| 60-A | Flyash, Philadelphia Electric Co., No. 65 flyash tank, Del. Ave. and Lewis St., Philadelphia, Pa. Carbon = 15.8 pct. |
| 61-A | Bituminous Char, Island Creek Coal Co., Holden, W. Va. |
| 62-A | Subbituminous B coal, Deitz seam, Big Horn Mine, Sheridan County, Wyo. |
| 63-A | Flyash, Philadelphia Electric Co., Tank No. 1A, Eddystone Station, Eddystone, Phila. County, Pa. Carbon - 5.27 pct. |

TABLE 2 - Identification of adsorbents tested in waste water treatment, cont'd

| Test No. | Adsorbent material and source |
|---|---|
| 64-A | High volatile A bituminous coal, Pittsburgh seam, U.S.B.M. Mine, Bruceton, Allegheny County, Pa. |
| 65-A | Subbituminous A coal, Upper Jack-O-Lantern seam, Kenwood Strip Mine of Beer Coal and Construction Co., Inc., Florence, Fremont County, Colorado. |

TABLE 3.- Analyses of coals, moisture-free basis

| | Anthracite, Kocher, sample 4-A | Anthracite, St. Nicholas, sample 5-A | Anthracite refuse, Greenwood, sample 31-A | Anthracite refuse, Kocher, sample 32-A | Anthracite refuse, St. Nicholas, sample 33-A | Semi-anthracite, Treverton, sample 41-A | Low vol. bit. C-prime, Upper Kittanning seam, sample 24-A | Low vol. bit. Lower Freeport "D" seam, sample 25-A | Low vol. bit. C-prime, Upper Kittanning seam, sample 26-A | Low vol. bit. Pocahontas #3 seam, sample 2-A | Medium vol. bit. Sewell seam, sample 40-A | Medium vol. bit. washer rejects, Sewell seam, sample 40-R |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Proximate analysis, pct: | | | | | | | | | | | | |
| Volatile matter | 7.0 | 4.1 | 5.8 | 7.5 | 6.3 | 9.8 | 19.6 | 18.7 | 18.0 | 16.4 | 26.9 | 14.4 |
| Fixed carbon | 82.4 | 84.8 | 21.2 | 27.3 | 21.3 | 82.1 | 71.2 | 72.6 | 71.8 | 77.3 | 69.4 | 20.9 |
| Ash | 10.6 | 11.1 | 73.0 | 65.2 | 72.4 | 8.1 | 9.2 | 8.7 | 10.2 | 5.8 | 3.7 | 64.7 |
| Ultimate analysis, pct: | | | | | | | | | | | | |
| Hydrogen | 2.9 | 2.0 | | | | 3.5 | 4.7 | 4.3 | 4.4 | 4.2 | 4.8 | 2.1 |
| Carbon | 83.1 | 83.8 | | | | 84.1 | 89.0 | 81.4 | 80.8 | 85.6 | 85.7 | 27.0 |
| Nitrogen | 1.1 | 0.8 | | | | 1.4 | 1.5 | 1.5 | 1.4 | 1.1 | 1.6 | 0.3 |
| Oxygen | 1.5 | 1.6 | | | | 1.9 | 2.1 | 2.2 | 1.0 | 2.7 | 3.6 | 4.9 |
| Sulfur | 0.8 | 0.7 | 1.3 | 0.5 | 1.2 | 1.0 | 2.7 | 1.9 | 2.2 | 0.6 | 0.6 | 1.0 |
| Ash | 10.6 | 11.1 | | | | 8.1 | | 8.7 | 10.2 | 5.8 | 3.7 | 64.7 |
| Btu/lb | 13,600 | 13,190 | | | | 14,160 | 14,210 | 14,290 | 13,990 | 14,690 | 15,030 | 4,820 |

Continued next page

TABLE 3.- Analyses of coals, moisture-free basis, cont'd

| | High vol. A bit., Pittsburgh seam, sample 64-A | High vol. B bit., Ohio #6 seam, sample 1-A | High vol. B. bit. washer rejects, Ohio #6 seam, sample 1-R | High vol. B bit., Kentucky #11 seam, sample 3-A | High vol. B bit. washer rejects, Kentucky #11 seam, sample 3-R | High vol. C bit., Sundance Mine, seam unknown, sample 8-A | High vol. C bit., Pioneer Cannon #1 mine, seam unknown, sample 10-A | High vol. C bit. washer rejects, Pioneer Cannon #1 mine, seam unknown, sample 10-R | High vol. C bit., Illinois #2 seam, sample 20-A | Sub. bit. A, Upper Jack-O-Lantern seam, sample 65-A | Sub. bit. B, Laramie seam coal, sample 9-A | Sub. bit. B, Elkhol Mine, sample 19-A | Sub. bit. B, Deitz seam coal, sample 62-A | Sub. bit. C, Smith Rolling seam, sample 6-A | Lignite Beulah Mine, seam unknown, sample 7-A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Proximate analysis, pct: | | | | | | | | | | | | | | | |
| Volatile matter | 36.4 | 39.6 | 25.2 | 39.7 | 16.3 | 43.6 | 38.1 | 29.6 | 48.8 | 42.2 | 37.3 | 46.1 | 41.9 | 43.9 | 41.9 |
| Fixed carbon | 55.0 | 54.6 | 28.3 | 51.3 | 14.3 | 50.0 | 52.7 | 34.6 | 44.5 | 53.2 | 55.6 | 49.0 | 52.9 | 44.7 | 49.9 |
| Ash | 8.6 | 5.8 | 46.5 | 9.0 | 69.4 | 6.4 | 9.2 | 35.8 | 6.7 | 4.6 | 7.1 | 4.9 | 5.2 | 11.4 | 8.2 |
| Ultimate analysis, pct: | | | | | | | | | | | | | | | |
| Hydrogen | 5.0 | 5.3 | 2.7 | 5.0 | 1.4 | 5.4 | 5.0 | 3.7 | 5.4 | 4.0 | 4.8 | 5.3 | 5.2 | 4.9 | 4.3 |
| Carbon | 76.4 | 78.0 | 35.3 | 71.8 | 16.1 | 73.6 | 70.3 | 47.1 | 74.9 | 66.3 | 70.6 | 74.0 | 71.4 | 65.2 | 65.6 |
| Nitrogen | 1.6 | 1.5 | 0.7 | 1.4 | 0.4 | 1.3 | 1.2 | 0.8 | 1.4 | 1.1 | 1.6 | 1.3 | 1.3 | 1.0 | 1.0 |
| Oxygen | 6.7 | 7.3 | | 9.0 | | 12.7 | 13.9 | 12.2 | 8.2 | 23.2 | 15.5 | 12.4 | 16.3 | 16.7 | 20.3 |
| Sulfur | 1.7 | 2.1 | 15.9 | 3.8 | 14.1 | 0.6 | 0.4 | 0.4 | 3.4 | 0.8 | 0.4 | 2.1 | 0.6 | 0.8 | 0.6 |
| Ash | 8.6 | 5.8 | 45.7 | 9.0 | 68.4 | 6.4 | 9.2 | 35.8 | 6.7 | 4.6 | 7.1 | 4.9 | 5.2 | 11.4 | 8.2 |
| Btu/lb | 13,630 | 14,070 | 6,940 | 12,950 | 3,130 | 13,070 | 12,230 | 8,170 | 13,640 | 10,880 | 12,150 | 13,170 | 12,460 | 11,290 | 10,910 |

necessary also since liquid samples removed for analytical determinations after testing with adsorbents were filtered with No. 5 Whatman paper to remove adsorbent particles; this filtration would have also removed the sewage particulate matter had it not been removed previously. Batches of stabilized, filtered effluents were stored in stainless steel containers under refrigeration (40° F) until used; stabilized effluents can thus be kept for a period of up to one month without appreciable degradation resulting.

## Testing Program

Basically two types of batch tests, designated screening and intensive, were employed in this study, differing only in the number of samples and adsorbent concentrations used. Each adsorbent tested was initially subjected to a screening test with the better adsorbents selected for more intensive testing. In the screening tests a single concentration of adsorbent (3 g/liter) was used. In the intensive tests five adsorbent concentrations were tested. In addition, several staged contacts were made in which the adsorbents were priodically contacted with fresh sewage until their saturation capacities for organics were reached or the adsorbent loss became too great. (Adsorbent losses were incurred in the normal handling process of recovering the adsorbent from one batch of sewage and replacing it in another.)

## Adsorbent Screening

Three liters of stabilized, filtered sewage was placed in a 4-liter Erlenmeyer flask which had been cleaned with chromic acid cleaning solution and rinsed with distilled water. Nine grams of the sized, dried adsorbent to be tested was placed in the flask with the sewage. The

stainless steel stirrer, which had also been cleaned with chromic acid solution, was inserted and the flask placed in the water bath. The mixture was stirred at a speed of 1,200-1,500 rpm; a speed sufficient to keep all the particles in suspension.

Two control samples were placed in test flasks in the water bath. One flask contained 9.0 grams of adsorbent and 3 liters of distilled water to determine whether the adsorbent being tested was contributing any contaminants. The other control sample contained 3 liters of sewage only to determine the changes in the COD and ABS concentration that occur in the sewage during the testing period.

The samples were stirred continuously for 24 hours at 22° C and were then analyzed for COD and ABS concentrations. All the liquid samples for analytical determinations were filtered through No. 5 Whatman paper to remove any suspended adsorbent particles which could have interfered with the analyses. At the beginning of the tests the sewage was analyzed for COD, ABS, TDS, pH, and conductivity. At the completion of each of the first few test runs the sewage was analyzed for these same components, but since only slight changes of pH, conductivity and total dissolved solids were occurring, these three analyses were eliminated in later tests. The following analytical test methods were used:

1. Chemical oxygen demand (COD) - Dichromate method[2/]
2. Alkyl Benzene Sulfonate (ABS) - Methylene Blue Method[3/]
3. Conductivity - Self-contained instrument[4/]
4. Total dissolved solids (TDS) - Evaporation[5/]
5. pH - Glass electrode[6/]

2/ "Elimination of Chloride Interference in the Chemical Oxygen Demand Test". Dobbs, R. A., and R. T. Williams. Paper presented before the Div. of Water and Waste Chemistry, American Chemical Society, Cincinnati, Ohio, January 14-16, 1963.

3/ "Standard Methods for the Examination of Water and Wastewater". Eleventh ed. 1960, pp. 245-248, as modified by Advanced Waste Treatment Research Center.

4/ Ibid. pp. 114-116.

5/ Ibid. pp. 326-327.

6/ Ibid. pp. 324-325.

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## RESULTS AND INTERPRETATIONS

### Screening Tests

Table 4 gives the results of the screening tests classified according to the adsorbents used and listed in the following classifications: Coals, activated carbon, flyashes, pre-treated coals, and miscellaneous. The tests with coals are listed according to decreasing rank of the coals. As the objective was merely to single out the most promising materials, the data were not suitable for extensive correlation. The amount of contaminant removal is determined from the difference in contaminants between the adsorbent-sewage sample and the sewage-only sample after 24 hours of stirring of each. For example, percent COD removal =

$$\frac{\text{(COD of sewage) minus (COD of adsorbent-sewage mixture)}}{\text{(COD of sewage)}}$$

Thus removal of contaminant effected by the 24-hour stirring period in air and any contaminants contributed by the adsorbent are taken into account.

TABLE 4 .- Results of screening tests with 3 g/liter adsorbent dosages (42-60 mesh) stirred with 3 liters of secondary sewage effluent at 22° C for 24 hours

| | Anthracite | | | | | Semi anthracite |
|---|---|---|---|---|---|---|
| | 4A-1 | 5A-1 | 31A-1 | 32A-1 | 33A-1 | 41A-1 |
| Chemical Oxygen Demand, ppm | | | | | | |
| Sewage plus adsorbent, | | | | | | |
| Stirred 2 hr | -- | 73 | -- | -- | -- | -- |
| Stirred 5 hr | -- | 71 | -- | -- | -- | -- |
| Stirred 24 hr | 63 | 56 | 34 | 48 | 19 | 41 |
| Sewage only, | | | | | | |
| Stabilized, filtered | 83 | 89 | 45 | 63 | 46 | 43 |
| Stirred 24 hr | 70 | 68 | 39 | 56 | 39 | 41 |
| Distilled water plus adsorbent, stirred 24 hr | 4 | 1 | 3 | 2 | 2 | 4 |
| Removal, 24 hr, pct | 10 | 18 | 13 | 14 | 51 | 0 |
| Alkyl Benzene Sulfonate, ppm | | | | | | |
| Sewage plus adsorbent, | | | | | | |
| Stirred 2 hr | -- | 5.7 | -- | -- | -- | -- |
| Stirred 5 hr | -- | 5.8 | -- | -- | -- | -- |
| Stirred 24 hr | 6.5 | 6.5 | 2.8 | 6.3 | 1.3 | 2.5 |
| Sewage only, | | | | | | |
| Stabilized, filtered | 6.7 | 6.7 | 2.9 | 6.7 | 3.2 | 3.1 |
| Stirred 24 hr | 6.8 | 6.5 | 3.1 | 6.9 | 3.0 | 2.8 |
| Distilled water plus adsorbent, stirred 24 hr | 0.3 | 1.0 | 0.2 | 0.3 | 0.1 | 0.3 |
| Removal, 24 hr, pct | 4 | 0 | 10 | 9 | 55 | 1 |
| pH | | | | | | |
| Sewage plus adsorbent, | | | | | | |
| Stirred 24 hr | | 8.0 | | | | |
| Sewage only, | | | | | | |
| Stabilized, filtered | 7.60 | 8.05 | 7.90 | 7.90 | 7.90 | 8.00 |
| Stirred 24 hr | | 8.0 | | | | |
| Distilled water plus adsorbent, stirred 24 hr | | 6.65 | | | | |
| Total dissolved solids, ppm | | | | | | |
| Sewage plus adsorbent, stirred 24 hr | | 734 | | | | |
| Sewage only, | | | | | | |
| Stabilized, filtered | 668 | 731 | 690 | 593 | 690 | 736 |
| Stirred 24 hr | | 726 | | | | |
| Distilled water plus adsorbent, stirred 24 hr | | 0 | | | | |
| Removal, 24 hr, pct | | -1 | | | | |
| Conductivity, micromhos/cm | | | | | | |
| Sewage plus adsorbent, stirred 24 hr | | 1310 | | | | |
| Sewage only, | | | | | | |
| Stabilized, filtered | 1127 | 1220 | 1065 | 915 | 1065 | 1174 |
| Stirred 24 hr | | 1290 | | | | |
| Distilled water plus adsorbent, stirred 24 hr | | 5 | | | | |
| Loss, 24 hr, pct | | -2 | | | | |

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TABLE 4 .- Results of screening tests with 3 g/liter adsorbent dosage (42-60 mesh) stirred with 3 liters of secondary sewage effluent at 22° C for 24 hours, cont'd

| | Low volatile bituminous | | | | | |
|---|---|---|---|---|---|---|
| | 2A-1 | 2A-2 | 2A-3 | 2A-4 | 2R-1 | 2R-2 |
| Chemical Oxygen Demand, ppm | | | | | | (6 g/liter dosage) |
| Sewage plus adsorbent, | | | | | | |
| Stirred 2 hr | 57 | -- | -- | -- | 52 | -- |
| Stirred 5 hr | 56 | -- | -- | -- | 52 | -- |
| Stirred 24 hr | 45 | 36 | 45 | 38 | 41 | 53 |
| Sewage only, | | | | | | |
| Stabilized, filtered | 60 | 44 | 65 | 61 | 60 | 72 |
| Stirred 24 hr | 52 | 38 | 57 | 57 | 56 | 66 |
| Distilled water plus adsorbent, stirred 24 hr | 0 | 3 | 13 | 7 | 2 | 6 |
| Removal, 24 hr, pct | 14 | 5 | 21 | 33 | 27 | 20 |
| Alkyl Benzene Sulfonate, ppm | | | | | | |
| Sewage plus adsorbent, | | | | | | |
| Stirred 2 hr | 5.1 | -- | -- | -- | 5.3 | -- |
| Stirred 5 hr | 5.1 | -- | -- | -- | 5.6 | -- |
| Stirred 24 hr | 5.1 | 2.6 | 1.4 | 2.5 | 6.0 | 6.3 |
| Sewage only, | | | | | | |
| Stabilized, filtered | 6.9 | 3.3 | 4.9 | 5.5 | 6.9 | 6.9 |
| Stirred 24 hr | 5.2 | 3.1 | 3.8 | 5.2 | 6.6 | 6.8 |
| Distilled water plus adsorbent, stirred 24 hr | tr. | 0.1 | 0.4 | 0.2 | tr. | 0.2 |
| Removal, 24 hr, pct | 2 | 16 | 63 | 52 | 9 | 7 |
| pH | | | | | | |
| Sewage plus adsorbent, stirred 24 hr | 8.35 | | | | 8.20 | 8.15 |
| Sewage only, | | | | | | |
| Stabilized, filtered | 8.32 | 7.90 | 8.00 | 7.90 | 8.32 | 8.05 |
| Stirred 24 hr | 8.20 | | | | 8.15 | 8.10 |
| Distilled water plus adsorbent, stirred 24 hr | 4.30 | | | | 7.00 | 7.45 |
| Total dissolved solids, ppm | | | | | | |
| Sewage plus adsorbent, stirred 24 hr | 688 | | | | 722 | 687 |
| Sewage only, | | | | | | |
| Stabilized, filtered | 653 | 690 | 973 | 1028 | 653 | 677 |
| Stirred 24 hr | 663 | | | | 690 | 698 |
| Distilled water plus adsorbent, stirred 24 hr | 0 | | | | 10 | 7 |
| Removal, 24 hr, pct | -4 | | | | -5 | 2 |
| Conductivity, micromhos/cm | | | | | | |
| Sewage plus adsorbent, stirred 24 hr | 1164 | | | | 1141 | 1070 |
| Sewage only, | | | | | | |
| Stabilized, filtered | 1012 | 1065 | 1545 | 1306 | 1012 | 1088 |
| Stirred 24 hr | 1170 | | | | 975 | 1065 |
| Distilled water plus adsorbent, stirred 24 hr | 32 | | | | 8 | 8 |
| Loss, 24 hr, pct | 1 | | | | -17 | -1 |

Continued next page

TABLE 4.- Results of screening tests with 3 g/liter adsorbent dosage (42-60 mesh) stirred with 3 liters of secondary sewage effluent at 22° C for 24 hours, cont'd

| | Low volatile bituminous | | | | | |
|---|---|---|---|---|---|---|
| | 24A-1 | 24A-2 | 25A-1 | 26A-1 | 26A-2 | 72A-1 |
| Chemical Oxygen Demand, ppm | | | | | | |
| Sewage plus adsorbent, | | | | | | |
| Stirred 2 hr | -- | -- | -- | -- | -- | -- |
| Stirred 5 hr | -- | -- | -- | -- | -- | -- |
| Stirred 24 hr | 52 | 61 | 59 | 40 | 63 | 33 |
| Sewage only, | | | | | | |
| Stabilized, filtered | 81 | 87 | 73 | 101 | 84 | 50 |
| Stirred 24 hr | 72 | 70 | 69 | 80 | 80 | 46 |
| Distilled water plus adsorbent, stirred 24 hr | 8 | 6 | 3 | 1 | 13 | 12 |
| Removal, 24 hr, pct | 28 | 13 | 15 | 50 | 21 | 28 |
| Alkyl Benzene Sulfonate, ppm | | | | | | |
| Sewage plus adsorbent, | | | | | | |
| Stirred 2 hr | -- | -- | -- | -- | -- | -- |
| Stirred 5 hr | -- | -- | -- | -- | -- | -- |
| Stirred 24 hr | 5.5 | 6.5 | 6.8 | 3.3 | 5.9 | 2.9 |
| Sewage only, | | | | | | |
| Stabilized, filtered | 7.0 | 6.7 | 7.3 | 7.3 | 6.7 | 5.0 |
| Stirred 24 hr | 7.3 | 6.8 | 7.3 | 6.5 | 6.7 | 4.7 |
| Distilled water plus adsorbent, stirred 24 hr | 0.4 | 0.3 | 0.3 | 0.3 | 0.2 | 0.2 |
| Removal, 24 hr, pct | 25 | 4 | 7 | 49 | 8 | 38 |
| pH | | | | | | |
| Sewage plus adsorbent, stirred 24 hr | 8.20 | | | | | |
| Sewage only, | | | | | | |
| Stabilized, filtered | 8.05 | 7.60 | 8.05 | 7.60 | 7.60 | 7.80 |
| Stirred 24 hr | 7.95 | | | | | |
| Distilled water plus adsorbent, stirred 24 hr | 6.90 | | | | | |
| Total dissolved solids, ppm | | | | | | |
| Sewage plus adsorbent, stirred 24 hr | 698 | | | | | |
| Sewage only, | | | | | | |
| Stabilized, filtered | 677 | 668 | 677 | 668 | 668 | 646 |
| Stirred 24 hr | 707 | | | | | |
| Distilled water plus adsorbent, stirred 24 hr | 13 | | | | | |
| Removal, 24 hr, pct | 1 | | | | | |
| Conductivity, micromhos/cm | | | | | | |
| Sewage plus adsorbent, stirred 24 hr | 1045 | | | | | |
| Sewage only, | | | | | | |
| Stabilized, filtered | 1088 | 1127 | 1088 | 1127 | 1127 | 898 |
| Stirred 24 hr | 1054 | | | | | |
| Distilled water plus adsorbent, stirred 24 hr | 9 | | | | | |
| Loss, 24 hr, pct | 1 | | | | | |

Continued next page

TABLE 4.- Results of screening tests with 3 g/liter adsorbent dosage (42-60 mesh) stirred with 3 liters of secondary sewage effluent at 22° C for 24 hours, cont'd

| | Medium volatile bituminous | | High volatile A bituminous | High volatile B bituminous | | | | |
|---|---|---|---|---|---|---|---|---|
| | 40A-1 | 40R-1 | 64A-1 | 1A7 | 1R1 | 3A1 | 3R1 | 3R2 |
| Chemical Oxygen Demand, ppm | | | | | | | | |
| Sewage plus adsorbent, | | | | | | | | |
| Stirred 2 hr | | | | 74 | | | | |
| Stirred 5 hr | | | | 70 | | | | |
| Stirred 24 hr | 38 | 44 | 48 | 60 | 58 | 34 | 37 | 59 |
| Sewage only, | | | | | | | | |
| Stabilized, filtered | 50 | 49 | 47 | 89 | 77 | 72 | 79 | 90 |
| Stirred 24 hr | 51 | 44 | 42 | 66 | 70 | 54 | 56 | 78 |
| Distilled water plus adsorbent, stirred 24 hr | 8 | 5 | 5 | 0 | 4 | 5 | 3 | 12 |
| Removal, 24 hr, pct | 25 | 0 | -14 | 9 | 17 | 37 | 34 | 24 |
| Alkyl Benzene Sulfonate, ppm | | | | | | | | |
| Sewage plus adsorbent, | | | | | | | | |
| Stirred 2 hr | | | | 5.8 | | | | |
| Stirred 5 hr | | | | 5.7 | | | | |
| Stirred 24 hr | 3.8 | 3.4 | 4.3 | 6.0 | 7.5 | 3.0 | 4.0 | 6.3 |
| Sewage only, | | | | | | | | |
| Stabilized, filtered | 3.9 | 3.3 | 4.9 | 6.7 | 8.2 | 4.3 | 4.1 | 8.1 |
| Stirred 24 hr | 3.9 | 3.9 | 4.6 | 6.4 | 7.9 | 3.8 | 4.3 | 7.5 |
| Distilled water plus adsorbent, stirred 24 hr | 0.7 | 0.6 | 0.3 | tr. | 0.5 | 0.4 | 0.6 | 0.4 |
| Removal, 24 hr, pct | .3 | 13 | 7 | 6 | 5 | 21 | 7 | 16 |
| pH | | | | | | | | |
| Sewage plus adsorbent, | | | | | | | | |
| Stirred 24 hr | | | | 8.15 | 8.00 | | | |
| Sewage only, | | | | | | | | |
| Stabilized, filtered | 7.80 | 8.00 | 8.10 | 8.05 | 8.01 | 7.95 | 7.95 | 7.70 |
| Stirred 24 hr | | | | 8.05 | 8.05 | | | |
| Distilled water plus adsorbent, stirred 24 hr | | | | 5.60 | 7.85 | | | |
| Total dissolved solids, ppm | | | | | | | | |
| Sewage plus adsorbent, stirred 24 hr | | | | 731 | 713 | | | |
| Sewage only, | | | | | | | | |
| Stabilized, filtered | 701 | 736 | 776 | 731 | 699 | 580 | 580 | 992 |
| Stirred 24 hr | | | | 739 | 699 | | | |
| Distilled water plus adsorbent, stirred 24 hr | | | | 10 | 42 | | | |
| Removal, 24 hr, pct | | | | 2 | -2 | | | |
| Conductivity, micromhos/cm | | | | | | | | |
| Sewage plus adsorbent, stirred 24 hr | | | | 1308 | 1151 | | | |
| Sewage only, | | | | | | | | |
| Stabilized, filtered | 1125 | 1174 | 947 | 1220 | 1167 | 973 | 973 | 1382 |
| Stirred 24 hr | | | | 1320 | 1140 | | | |
| Distilled water plus adsorbent, stirred 24 hr | | | | 13 | 77 | | | |
| Loss, 24 hr, pct | | | | 2 | -1 | | | |

Continued next page

TABLE 4.- Results of screening tests with 3 g/liter adsorbent dosage (42-60 mesh) stirred with 3 liters of secondary sewage effluent at 22° C for 24 hours, cont'd

| | High volatile C bituminous | | | | | |
|---|---|---|---|---|---|---|
| | 8A-1 | 10A-1 | 10A-2 | 10R-1 | 20A-1 | 20A-2 |
| Chemical Oxygen Demand, ppm | | | | | | |
| Sewage plus adsorbent, | | | | | | |
| Stirred 2 hr | -- | -- | -- | -- | -- | -- |
| Stirred 5 hr | -- | -- | -- | -- | -- | -- |
| Stirred 24 hr | 39 | 40 | 61 | 59 | 75 | 30 |
| Sewage only, | | | | | | |
| Stabilized, filtered | 66 | 70 | 90 | 79 | 64 | 79 |
| Stirred 24 hr | 47 | 60 | 78 | 68 | 53 | 52 |
| Distilled water plus adsorbent, stirred 24 hr | 2 | 3 | 15 | 5 | 12 | 6 |
| Removal, 24 hr, pct | 17 | 33 | 22 | 13 | -42 | 42 |
| Alkyl Benzene Sulfonate, ppm | | | | | | |
| Sewage plus adsorbent, | | | | | | |
| Stirred 2 hr | -- | -- | -- | -- | -- | -- |
| Stirred 5 hr | -- | -- | -- | -- | -- | -- |
| Stirred 24 hr | 3.3 | 5.6 | 5.9 | 7.1 | 4.2 | 1.5 |
| Sewage only, | | | | | | |
| Stabilized, filtered | 3.9 | 7.6 | 8.1 | 8.2 | 6.7 | 6.0 |
| Stirred 24 hr | 4.1 | 6.5 | 7.5 | 7.5 | 6.6 | 4.9 |
| Distilled water plus adsorbent, stirred 24 hr | 0.4 | 0.5 | 0.4 | tr. | 0.2 | 0.2 |
| Removal, 24 hr, pct | 20 | 14 | 21 | 5 | 36 | 69 |
| pH | | | | | | |
| Sewage plus adsorbent, stirred 24 hr | | | | 8.00 | | 8.05 |
| Sewage only, | | | | | | |
| Stabilized, filtered | 7.95 | 7.90 | 7.70 | 8.01 | 7.90 | 7.98 |
| Stirred 24 hr | | | | 8.60 | | 8.15 |
| Distilled water plus adsorbent, stirred 24 hr | | | | 7.01 | | 3.60 |
| Total dissolved solids, ppm | | | | | | |
| Sewage plus adsorbent, stirred 24 hr | | | | 695 | | |
| Sewage only, | | | | | | |
| Stabilized, filtered | 580 | 593 | 992 | 699 | 593 | 666 |
| Stirred 24 hr | | | | 705 | | |
| Distilled water plus adsorbent, stirred 24 hr | | | | 7 | | |
| Removal, 24 hr, pct | | | | 1 | | |
| Conductivity, micromhos/cm | | | | | | |
| Sewage plus adsorbent, stirred 24 hr | | | | 1136 | | |
| Sewage only, | | | | | | |
| Stabilized, filtered | 973 | 915 | 1382 | 1167 | 915 | 853 |
| Stirred 24 hr | | | | 1150 | | |
| Distilled water plus adsorbent, stirred 24 hr | | | | 16 | | |
| Loss, 24 hr, pct | | | | 1 | | |

Continued next page

TABLE 4.- Results of screening tests with 3 g/liter adsorbent dosage (42-60 mesh) stirred with 3 liters of secondary sewage effluent at 22° C for 24 hours, cont'd

| | Sub-bituminous A | Sub-bituminous B | | | Sub-bituminous C | Lignite |
|---|---|---|---|---|---|---|
| | 65A-1 | 9A-1 | 19A-1 | 62A-1 | 6A-1 | 7A-1 |
| Chemical Oxygen Demand, ppm | | | | | | |
| Sewage plus adsorbent, | | | | | | |
| Stirred 2 hr | -- | -- | -- | -- | -- | -- |
| Stirred 5 hr | -- | -- | -- | -- | -- | -- |
| Stirred 24 hr | 59 | 28 | 46 | 38 | 41 | 48 |
| Sewage only, | | | | | | |
| Stabilized, filtered | -- | 64 | 64 | 47 | 71 | 95 |
| Stirred 24 hr | 44 | 50 | 56 | 45 | 52 | 72 |
| Distilled water plus adsorbent, stirred 24 hr | 75 | 7 | 3 | 9 | 21 | 17 |
| Removal, 24 hr, pct | -34 | 44 | 18 | 16 | 21 | 33 |
| Alkyl Benzene Sulfonate, ppm | | | | | | |
| Sewage plus adsorbent, | | | | | | |
| Stirred 2 hr | -- | -- | -- | -- | -- | -- |
| Stirred 5 hr | -- | -- | -- | -- | -- | -- |
| Stirred 24 hr | 4.2 | 2.2 | 5.9 | 3.8 | 3.2 | 4.8 |
| Sewage only, | | | | | | |
| Stabilized, filtered | -- | 4.1 | 6.9 | 4.8 | 4.1 | 7.2 |
| Stirred 24 hr | 4.4 | 4.4 | 6.8 | 4.6 | 4.0 | 6.8 |
| Distilled water plus adsorbent, stirred 24 hr | 0.8 | 0.5 | 0.3 | 0.3 | 0.5 | 0.4 |
| Removal, 24 hr, pct | 5 | 50 | 13 | 17 | 20 | 29 |
| pH | | | | | | |
| Sewage plus adsorbent, stirred 24 hr | | | | | | |
| Sewage only, | | | | | | |
| Stabilized, filtered | 8.20 | 7.95 | 7.90 | 8.10 | 7.95 | 7.60 |
| Stirred 24 hr | | | | | | |
| Distilled water plus adsorbent, stirred 24 hr | | | | | | |
| Total dissolved solids, ppm | | | | | | |
| Sewage plus adsorbent, stirred 24 hr | | | | | | |
| Sewage only, | | | | | | |
| Stabilized, filtered | 680 | 580 | 593 | 776 | 580 | 668 |
| Stirred 24 hr | | | | | | |
| Distilled water plus adsorbent, stirred 24 hr | | | | | | |
| Removal, 24 hr, pct | | | | | | |
| Conductivity, micromhos/cm | | | | | | |
| Sewage plus adsorbent, stirred 24 hr | | | | | | |
| Sewage only, | | | | | | |
| Stabilized, filtered | 811 | 973 | 915 | 947 | 973 | 1127 |
| Stirred 24 hr | | | | | | |
| Distilled water plus adsorbent, stirred 24 hr | | | | | | |
| Loss, 24 hr, pct | | | | | | |

Continued next page

TABLE 4 .- Results of screening tests with 3 g/liter adsorbent dosage (42-60 mesh) stirred with 3 liters of secondary sewage effluent at 22° C for 24 hours, cont'd

| | Activated carbon | | |
|---|---|---|---|
| | 23A-1 (8-30 mesh) | 23A-2 | 23A-3 (6.0 g/l) |
| Chemical Oxygen Demand, ppm | | | |
| Sewage plus adsorbent, | | | |
| Stirred 2 hr | | 24 | |
| Stirred 5 hr | | 14 | |
| Stirred 24 hr | 9 | 7 | 4 |
| Sewage only, | | | |
| Stabilized, filtered | 49 | 60 | 77 |
| Stirred 24 hr | 50 | 58 | 69 |
| Distilled water plus adsorbent, stirred 24 hr | | 0 | 0 |
| Removal, 24 hr, pct | 82 | 88 | 94 |
| Alkyl Benzene Sulfonate, ppm | | | |
| Sewage plus adsorbent, | | | |
| Stirred 2 hr | | 0.1 | |
| Stirred 5 hr | | tr. | |
| Stirred 24 hr | 0.2 | tr. | tr. |
| Sewage only, | | | |
| Stabilized, filtered | 6.1 | 6.9 | 7.7 |
| Stirred 24 hr | 6.0 | 5.1 | 6.9 |
| Distilled water plus adsorbent, stirred 24 hr | -- | 0.1 | tr. |
| Removal, 24 hr, pct | 98 | 100 | 100 |
| pH | | | |
| Sewage plus adsorbent, | | | |
| Stirred 24 hr | | 8.20 | 8.45 |
| Sewage only, | | | |
| Stabilized, filtered | 8.00 | 8.32 | 8.05 |
| Stirred 24 hr | | 6.05 | 8.00 |
| Distilled water plus adsorbent, stirred 24 hr | | 5.65 | 7.30 |
| Total dissolved solids, ppm | | | |
| Sewage plus adsorbent, stirred 24 hr | | 688 | 596 |
| Sewage only, | | | |
| Stabilized, filtered | 596 | 653 | 677 |
| Stirred 24 hr | | 811 | 657 |
| Distilled water plus adsorbent, stirred 24 hr | | 16 | 8 |
| Removal, 24 hr, pct | | 15 | 9 |
| Conductivity, micromhos/cm | | | |
| Sewage plus adsorbent, stirred 24 hr | | 985 | 1074 |
| Sewage only, | | | |
| Stabilized, filtered | 993 | 1012 | 1088 |
| Stirred 24 hr | | 985 | 1080 |
| Distilled water plus adsorbent, stirred 24 hr | | 17 | 14 |
| Loss, 24 hr, pct | | 0 | 1 |

Continued next page

TABLE 4.- Results of screening tests with 3 g/liter adsorbent dos
of secondary sewage effluent at 22° C

| | Flyashes | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 34A-1 (washed) | 34A-3 | 34R-1 | 35A-1 | 42A-1 (washed) | 42A-2 | 43A-1 (washed) | 50A-1 | 52A-1 |
| Carbon, pct | | 35.3 | | 6.0 | 2.0 | 2.0 | 6.0 | 2.4 | 6.7 |
| Chemical Oxygen Demand, ppm | | | | | | | | | |
| Sewage plus adsorbent | | | | | | | | | |
| Stirred 2 hr | | | | | | | | | |
| Stirred 5 hr | | | | | | | | | |
| Stirred 24 hr | 29 | 8 | 22 | 33 | 35 | 39 | 30 | 50 | 40 |
| Sewage only, | | | | | | | | | |
| Stabilized, filtered | 71 | 53 | 29 | 74 | 57 | 53 | 55 | 78 | 65 |
| Stirred 24 hr | 67 | 47 | 28 | 57 | 45 | 47 | 48 | 76 | 57 |
| Distilled water plus adsorbent, stirred 24 hr | 2 | 0 | 3 | 0 | 6 | 2 | 0 | 4 | 14 |
| Removal, 24 hr, pct | 57 | 83 | 21 | 42 | 22 | 17 | 38 | 34 | 30 |
| Alkyl Benzene Sulfonate, ppm | | | | | | | | | |
| Sewage plus adsorbent | | | | | | | | | |
| Stirred 2 hr | | | | | | | | | |
| Stirred 5 hr | | | | | | | | | |
| Stirred 24 hr | 3.4 | 3.9 | 2.2 | 4.5 | 3.0 | 6.4 | 2.6 | 7.0 | 2.0 |
| Sewage only | | | | | | | | | |
| Stabilized, filtered | 6.0 | 6.4 | 5.7 | 5.8 | 3.5 | 6.4 | 3.7 | 8.8 | 4.9 |
| Stirred 24 hr | 5.6 | 6.3 | 6.2 | 5.2 | 3.6 | 6.3 | 3.8 | 8.3 | 3.8 |
| Distilled water plus adsorbent, stirred 24 hr | 0.1 | 0.3 | 0.2 | 0.2 | 0.1 | 0.4 | 0.4 | 0.3 | 0.3 |
| Removal, 24 hr, pct | 39 | 38 | 65 | 13 | 17 | -2 | 32 | 16 | 47 |
| pH | | | | | | | | | |
| Sewage plus adsorbent, stirred 24 hr | | | | | | | | | |
| Sewage only | | | | | | | | | |
| Stabilized, filtered | 7.98 | 6.90 | 6.90 | 7.80 | 7.80 | 6.90 | 7.80 | 7.85 | 8.00 |
| Stirred 24 hr | | | | | | | | | |
| Distilled water plus adsorbent, stirred 24 hr | | | | | | | | | |
| Total dissolved solids, ppm | | | | | | | | | |
| Sewage plus adsorbent, stirred 24 hr | | | | | | | | | |
| Sewage only | | | | | | | | | |
| Stabilized, filtered | 666 | 763 | 848 | 750 | 701 | 763 | 701 | 972 | 973 |
| Stirred 24 hr | | | | | | | | | |
| Distilled water plus adsorbent, stirred 24 hr | | | | | | | | | |
| Removal, 24 hr, pct | | | | | | | | | |
| Conductivity, micromhos/cm | | | | | | | | | |
| Sewage plus adsorbent, stirred 24 hr | | | | | | | | | |
| Sewage only | | | | | | | | | |
| Stabilized, filtered | 853 | 940 | 1095 | 1115 | 1125 | 940 | 1125 | 1413 | 1545 |
| Stirred 24 hr | | | | | | | | | |
| Distilled water plus adsorbent, stirred 24 hr | | | | | | | | | |
| Loss, 24 hr, pct | | | | | | | | | |

with 3 g/liter adsorbent dosage (42-60 mesh) stirred with 3 liters
ry sewage effluent at 22° C for 24 hours, cont'd

| | Flyashes (unsieved) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 42A-2 | 43A-1 (washed) | 50A-1 | 52A-1 | 53A-1 | 54A-1 | 56A-1 | 57A-1 | 58A-1 | 59A-1 | 60A-1 | 63A-1 |
| 2.0 | 6.0 | 2.4 | 6.7 | 5.3 | 20.4 | 2.7 | 0.9 | 4.5 | 0.1 | 15.8 | 5.3 |
| 39 | 30 | 50 | 40 | 46 | 31 | 49 | 47 | 46 | 62 | 46 | 50 |
| 53 | 55 | 78 | 65 | 61 | 62 | 62 | 61 | 61 | 94 | 94 | 71 |
| 47 | 48 | 76 | 57 | 57 | 60 | 60 | 59 | 59 | 80 | 80 | 65 |
| 2 | 0 | 4 | 14 | 6 | 3 | 8 | 6 | 9 | 7 | 5 | 9 |
| 17 | 38 | 34 | 30 | 19 | 48 | 18 | 20 | 22 | 23 | 43 | 23 |
| 6.4 | 2.6 | 7.0 | 2.0 | 5.4 | 2.2 | 5.7 | 5.6 | 4.5 | 7.0 | 4.2 | 4.9 |
| 6.4 | 3.7 | 8.8 | 4.9 | 5.5 | 6.6 | 6.6 | 6.7 | 6.7 | 8.1 | 8.1 | 6.6 |
| 6.3 | 3.8 | 8.3 | 3.8 | 5.2 | 6.4 | 6.4 | 6.0 | 6.0 | 7.4 | 7.4 | 5.7 |
| 0.4 | 0.4 | 0.3 | 0.3 | 0.2 | 0.3 | 0.3 | 0.3 | 0.2 | 0.1 | 0.2 | 0.3 |
| -2 | 32 | 16 | 47 | -4 | 66 | 11 | 7 | 25 | 5 | 43 | 14 |
| .90 | 7.80 | 7.85 | 8.00 | 7.90 | 7.90 | 7.90 | 7.90 | 7.90 | 7.70 | 7.70 | 7.50 |
| 763 | 701 | 972 | 973 | 1028 | 1028 | 1028 | 1028 | 1028 | 992 | 992 | 766 |
| 940 | 1125 | 1413 | 1545 | 1306 | 1306 | 1306 | 1306 | 1306 | 1382 | 1382 | 1053 |

Continued next page

TABLE 4.-Results of screening tests with 3 g/liter adsorbent dosage of secondary sewage effluent at 22° C for

| | Pretreated coals (42- | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Coal Rank | 11A-1 | 12A-1 | 13A-1 | 14A-1 | 15A-1 | 16A-1 | 28A-1 | 29A-1 | 30A-1 | 36A-1 | 37A-1 | 37 |
| | hvab | hvab | hvab | hvab | hvab | hvab 1/ | hvab | hvab | lvb | lvb | hvab | h |
| Raw coal No. | 64A | 64A | 64A | 64A | 64A | 64A | 64A | 64A | 24A | 26A | 64A | 6 |
| Chemical Oxygen Demand, ppm | | | | | | | | | | | | |
| Sewage plus adsorbent | | | | | | | | | | | | |
| Stirred 2 hr | 64 | | 76 | 73 | 75 | | | | | | | |
| Stirred 5 hr | 62 | | 73 | 67 | 71 | | | | | | | |
| Stirred 24 hr | 58 | 32 | 60 | 56 | 73 | 31 | 42 | 39 | 41 | 41 | 35 | |
| Sewage only | | | | | | | | | | | | |
| Stabilized, filtered | 78 | 43 | 87 | 82 | 87 | 41 | 62 | 79 | 80 | 69 | 49 | |
| Stirred 24 hr | 64 | 37 | 66 | 69 | 71 | 39 | 58 | 60 | 63 | 58 | 45 | |
| Distilled water plus adsorbent, stirred 24 hr | 0 | 5 | 0 | 2 | 4 | 1 | 1 | tr. | 3 | 0 | 4 | |
| Removal, 24 hr, pct | 9 | 14 | 9 | 16 | -3 | 21 | 28 | 35 | 35 | 29 | 22 | |
| Alkyl Benzene Sulfonate, ppm | | | | | | | | | | | | |
| Sewage plus adsorbent | | | | | | | | | | | | |
| Stirred 2 hr | 5.2 | | 6.2 | 6.0 | 6.0 | | | | | | | |
| Stirred 5 hr | 5.0 | | 6.2 | 6.0 | 5.9 | | | | | | | |
| Stirred 24 hr | 5.7 | 4.7 | 6.6 | 6.6 | 6.6 | 2.3 | 4.7 | 3.1 | 4.2 | 4.2 | 2.7 | 2. |
| Sewage only | | | | | | | | | | | | |
| Stabilized, filtered | 6.2 | 4.4 | 7.3 | 7.3 | 7.3 | 3.1 | 6.8 | 6.2 | 6.0 | 6.1 | 3.0 | 3. |
| Stirred 24 hr | 6.5 | 4.9 | 6.7 | 7.2 | 6.8 | 3.1 | 6.9 | 5.9 | 5.4 | 5.3 | 2.9 | 3. |
| Distilled water plus adsorbent, stirred 24 hr | 0 | 0.4 | 0 | 0.4 | 0 | 0.3 | 0.2 | 0.3 | 0.3 | 0.1 | 0.2 | 0. |
| Removal, 24 hr, pct | 12 | 5 | 2 | 8 | 3 | 26 | 32 | 48 | 22 | 21 | 7 | 3 |
| pH | | | | | | | | | | | | |
| Sewage plus adsorbent, stirred 24 hr | 7.9 | | 8.03 | 8.03 | 7.92 | | | | | | | |
| Sewage only | | | | | | | | | | | | |
| Stabilized, filtered | 8.05 | 8.00 | 8.15 | 8.15 | 8.15 | 7.90 | 7.90 | 7.98 | 7.80 | 7.80 | 7.90 | 7.8 |
| Stirred 24 hr | 8.05 | | 8.15 | 8.30 | 8.08 | | | | | | | |
| Distilled water plus adsorbent, stirred 24 hr | 7.07 | | 4.72 | 6.91 | 7.32 | | | | | | | |
| Total dissolved solids, ppm | | | | | | | | | | | | |
| Sewage plus adsorbent, stirred 24 hr | 705 | | 728 | 745 | 745 | | | | | | | |
| Sewage only | | | | | | | | | | | | |
| Stabilized, filtered | 731 | 581 | 725 | 725 | 725 | 690 | 593 | 666 | 750 | 750 | 690 | 701 |
| Stirred 24 hr | 687 | | 720 | 735 | 757 | | | | | | | |
| Distilled water plus adsorbent, stirred 24 hr | 0 | | 12 | 16 | 22 | | | | | | | |
| Removal, 24 hr, pct | -3 | | -1 | -1 | 2 | | | | | | | |
| Conductivity, micromhos/cm | | | | | | | | | | | | |
| Sewage plus adsorbent, stirred 24 hr | 1259 | | 1047 | 1258 | 1236 | | | | | | | |
| Sewage only | | | | | | | | | | | | |
| Stabilized, filtered | 1220 | 959 | 1249 | 1249 | 1249 | 1065 | 915 | 853 | 1115 | 1115 | 1065 | 1125 |
| Stirred 24 hr | 1301 | | 1027 | 1220 | 1224 | | | | | | | |
| Distilled water plus adsorbent, stirred 24 hr | 7 | | 11 | 8 | 14 | | | | | | | |
| Loss, 24 hr, pct | 3 | - | -2 | -3 | -1 | - | | | | | | |

1/ Unsieved.

g/liter adsorbent dosage (42-60 mesh) stirred with 3 liters
wage effluent at 22° C for 24 hours, cont'd

| Pretreated coals (42-60 mesh) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 29A-1 | 30A-1 | 36A-1 | 37A-1 | 37A-2 | 38A-1 | 44A-1 | 45A-1 | 46A-1 | 47A-1 | 48A-1 | 49A-1 | 51A-1 |
| hvab | lvb | lvb | hvab | hvab | lvb | lignite char | lvb | lvb | lvb | lvb | lvb | lvb |
| 64A | 24A | 26A | 64A | 64A | 2A | | 2A | 2A | 2A | 2A | 2A | 2A |
| 39 | 41 | 41 | 35 | 34 | 31 | 54 | 75 | 67 | 77 | 59 | 59 | 55 |
| 79 | 80 | 69 | 49 | 55 | 70 | 49 | 99 | 99 | 84 | 84 | 86 | 86 |
| 60 | 63 | 58 | 45 | 45 | 61 | 49 | 91 | 91 | 81 | 81 | 78 | 78 |
| tr. | 3 | 0 | 4 | 9 | 5 | 8 | 5 | 1 | 9 | 5 | 4 | 4 |
| 35 | 35 | 29 | 22 | 24 | 49 | -10 | 18 | 26 | 5 | 27 | 24 | 30 |
| 3.1 | 4.2 | 4.2 | 2.7 | 2.0 | 2.5 | 5.4 | 7.7 | 5.4 | 6.8 | 4.3 | 5.9 | 6.2 |
| 6.2 | 6.0 | 6.1 | 3.0 | 3.8 | 5.9 | 5.6 | 10.5 | 10.5 | 10.1 | 10.1 | 9.5 | 9.5 |
| 5.9 | 5.4 | 5.3 | 2.9 | 3.3 | 5.4 | 5.5 | 10.1 | 10.1 | 8.6 | 8.6 | 8.8 | 8.8 |
| 0.3 | 0.3 | 0.1 | 0.2 | 0.1 | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 | 0.1 | 0.2 |
| 48 | 22 | 21 | 7 | 39 | 54 | 2 | 24 | 46 | 21 | 50 | 33 | 30 |
| 7.98 | 7.80 | 7.80 | 7.90 | 7.80 | 7.80 | 6.75 | 7.70 | 7.70 | 7.85 | 7.85 | 7.85 | 7.85 |
| 666 | 750 | 750 | 690 | 701 | 750 | 663 | 964 | 964 | 972 | 972 | 972 | 972 |
| 853 | 1115 | 1115 | 1065 | 1125 | 1115 | 1025 | 1372 | 1372 | 1413 | 1413 | 1413 | 1413 |

Continued next page

TABLE 4.- Results of screening tests with 3 g/liter adsorbent dosage (42-60 mesh) stirred with 3 liters of secondary sewage effluent at 22° C for 24 hours, cont'd

| | Miscellaneous | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Met coke 17A-1 | Met coke 18A-1 | Mont char 21A-1 | Disco 22A-1 | Coal ashes 27A-1 1/ | Steel mill slag 39A-1 | Michigan peat 55A-1 1/ | Bituminous char 61A-1 |
| Chemical Oxygen Demand, ppm | | | | | | | | |
| Sewage plus adsorbent | | | | | | | | |
| Stirred 2 hr | -- | -- | -- | -- | -- | -- | --- | -- |
| Stirred 5 hr | -- | -- | -- | -- | -- | -- | -- | --- |
| Stirred 24 hr | 66 | 33 | 62 | 70 | 44 | 45 | 178 | 61 |
| Sewage only | | | | | | | | |
| Stabilized, filtered | 83 | 40 | 74 | 79 | 71 | 70 | 83 | 71 |
| Stirred 24 hr | 70 | 39 | 66 | 70 | 58 | 59 | 80 | 65 |
| Distilled water plus adsorbent, stirred 24 hr | 4 | 0 | 1 | 6 | 1 | 7 | 118 | 8 |
| Removal, 24 hr, pct | 6 | 15 | 6 | 0 | 24 | 24 | -55 | 6 |
| Alkyl Benzene Sulfonate, ppm | | | | | | | | |
| Sewage plus adsorbent | | | | | | | | |
| Stirred 2 hr | -- | -- | -- | -- | -- | -- | -- | -- |
| Stirred 5 hr | -- | -- | -- | -- | -- | -- | -- | -- |
| Stirred 24 hr | 7.9 | 4.6 | 7.8 | 7.1 | 5.1 | 5.3 | 4.3 | 4.8 |
| Sewage only | | | | | | | | |
| Stabilized, filtered | 8.2 | 4.5 | 8.2 | 7.7 | 5.9 | 5.9 | 8.6 | 6.6 |
| Stirred 24 hr | 7.9 | 4.8 | 7.7 | 7.1 | 5.9 | 5.5 | 8.2 | 5.7 |
| Distilled water plus adsorbent, stirred 24 hr | 0.4 | 0.5 | 0.4 | 0.2 | 0.3 | 0.3 | 0.6 | 0.3 |
| Removal, 24 hr, pct | 0 | 4 | -1 | 0 | 14 | 4 | 48 | 16 |
| pH | | | | | | | | |
| Sewage plus adsorbent, stirred 24 hr | 8.1 | | 7.97 | 8.05 | | | | |
| Sewage only | | | | | | | | |
| Stabilized, filtered | 8.01 | 8.00 | 8.01 | 8.05 | 7.98 | 7.80 | 7.85 | 7.50 |
| Stirred 24 hr | 8.17 | | 7.98 | 8.30 | | | | |
| Distilled water plus adsorbent, stirred 24 hr | 6.53 | | 5.47 | 7.70 | | | | |
| Total dissolved solids, ppm | | | | | | | | |
| Sewage plus adsorbent, stirred 24 hr | 688 | | 694 | 665 | | | | |
| Sewage only | | | | | | | | |
| Stabilized, filtered | 699 | 581 | 699 | 677 | 666 | 750 | 972 | 766 |
| Stirred 24 hr | 684 | | 701 | 669 | | | | |
| Distilled water plus adsorbent, stirred 24 hr | 14 | | 4 | 26 | | | | |
| Removal, 24 hr, pct | -1 | | 1 | 1 | | | | |
| Conductivity, micromhos/cm | | | | | | | | |
| Sewage plus adsorbent, stirred 24 hr | 1169 | | 1158 | 1088 | | | | |
| Sewage only | | | | | | | | |
| Stabilized, filtered | 1167 | 959 | 1167 | 1088 | 853 | 1115 | 1413 | 1053 |
| Stirred 24 hr | 1161 | | 1160 | 1087 | | | | |
| Distilled water plus adsorbent, stirred 24 hr | 9 | | 11 | 37 | | | | |
| Loss, 24 hr, pct | -1 | | 0 | 0 | | | | |

1/ Unsieved.

The TDS removal and changes in conductivity and pH were very small so that these analyses were eliminated after a few initial tests. However, these analyses were made on the stabilized filtered sewage to indicate their range of values.

The results of the screening tests of various types of material can be summarized briefly.

Anthracite: With the exception of test 33A-1 in which 51 percent of the COD was removed, the anthracite coals were generally poor adsorbents.

Low and medium volatile bituminous: Of the 14 tests made with coals in these groups only two resulted in greater than 30 percent COD removal; tests 2A-4 giving 33 percent, and 26A-1, giving 50 percent COD removal. Repetitive tests with these same coals did not duplicate the results, COD removals of 14, 5, and 21 percent being obtained in tests 2A-1, 2A-2, and 2A-3, respectively, while test 26A-2 resulted in only 21 percent COD removal. In test 2R-2 the adsorbent dosage was doubled (6 g/liter) but the COD removal obtained, 20 percent, was less than that obtained with half as much of the same adsorbent (test 2R-1), 27 percent.

In general throughout the tests, duplication of results with the same adsorbent was not good despite efforts to maintain constant test conditions. Possibly all samples of each coal were not of uniform composition, the nonhomogeneity originating in the original sampling, grinding, washing sieving, or weighing operations. Since different sewage samples obtained at different times and even at different treatment plants were used in the testing program, nonconformity of these samples could also account for some differences in results. Although both

treatment plants used as supply sources of waste effluent treated essentially domestic sewage, the COD and ABS contents varied from day to day, and probably those individual compounds which make up COD varied as well. Thus the amount of refractory material could vary, depending on when the sample was obtained. Despite the problem of obtaining duplicate results, the objective of the screening program was met in that at least a qualitative indication of relative merits of the various materials as adsorbents could be obtained.

High volatile A, B, and C bituminous: In the 12 screening tests with high volatile rank coals, greater than 30 percent COD removal was obtained in 4 tests, 3A-1, 3R-1, 10A-1, and 20A-2. In test 3R-1 coal rejects or the discarded material from the coal cleaning process was used, resulting in 34 percent COD removal. Coal rejects or refuses are presently discarded as valueless. The amount of bituminous coal refuse produced annually is considerable, amounting to 58 million net tons in 1962, or about 20 percent of the total cleaned. ("Bureau of Mines Minerals Yearbook, 1962, v. II, Fuels, p. 111".)

Several of these high volatile coals contributed COD to the sewage so that the COD content of the treated sewages was greater than that of the untreated (tests 6A-1 and 20A-1). The coal used in test 20A-2, in addition to giving a high degree of removal of COD, removed 69 percent of the ABS present, reducing it from 4.9 to 1.5 ppm in the 24-hour contact period.

Sub-bituminous A, B, and C, and lignite: Of the six coals tested in this group, two removed more than 30 percent COD. The sub-bituminous B coal of test 9A-1 removed 44 percent COD and 50 percent ABS, while the lignite used in test 7A-1 removed 33 percent of the COD and 29 percent of the ABS.

Activated carbon: Test results obtained with Pittsburgh Chemical Company activated carbon type SGL have been used as a basis of comparison for the results obtained with coals and other materials tested in this study. Three screening tests were made with activated carbon as listed in table 4. In test 23A-1, 8-30 mesh particles were used, while in tests 23A-2 and 23A-3 42-60 mesh size was utilized. The 8-30 mesh carbon removed almost as much COD as the 42-60 mesh, 82 percent compared to 88 percent. Ninety-eight percent of the ABS was removed by the 8-30 mesh carbon compared to 100-percent removal with 42-60 mesh.

The adsorbent dosage was doubled (6.0 g/liter) in test 23A-3, but the COD removal was not greatly increased, 94 percent being removed as compared to 88 percent with 3 g/liter dosage. This indicates the presence of some material virtually not removable by adsorption.

In test 23A-2 after only two hours of contact with sewage, the carbon had removed 52 percent of the COD and practically all of the ABS. After five hours of contact, 76 percent of the COD and all of the ABS had been removed. Thus activated carbon adsorbs organic waste materials much more rapidly as well as more completely than did any of the coals tested.

Flyashes: The flyashes used in the screening tests were not sieved to size as were the coals, but were used as received. With the exception of tests 34A-1, 42A-1, and 43A-1, the flyashes were not washed with distilled water prior to drying. Test 34R-1 used the material that floated when the flyash of test 34A-1 was washed with distilled water, while this same flyash, unwashed, was used in test 34A-3.

Of the 17 screening tests with flyashes, COD removals of 30 percent or greater were obtained in nine tests. In general, the effectiveness of flyash as an adsorbent is dependent on the amount of carbon it contains, effectiveness increasing with the carbon content. This is illustrated in the screening test results shown in figure 4. Carbon percentages in the flyash varied from 0.9 to 35.3 and COD removals from 17 to 83 percent. The highest carbon content of 35.3 percent is not representative of typical commercial operations, but several of the commercial powerplant flyashes tested contained greater than 15 percent carbon.

The use of flyash as an adsorbent for waste water treatment would provide an attractive application for a waste product currently presenting a costly disposal problem to power generating stations. A conservative estimate is that about 10 million tons of flyash are produced annually by power generating stations burning powdered coal. The bulk of this material is discarded although small quantities are consumed in the cement industry. (Journal of the Air Pollution Control Assoc., v. 14, No. 3, Mar. 1964, p. 98.) If flyash were used as an adsorbent, it would require the usual disposal as land fill, etc., but at least the cost of handling and transport could be assigned to the treatment process.

Pretreated coals: Since the activated carbon used as a reference in this study is made by activating bituminous coals in a complex treatment process, attempts were made to partially treat raw coal in order to develop an adsorbent more efficient than the raw coal but less costly than carbon. (Results of screening tests with these materials are listed in table 4 under "pretreated coals".) Various pretreatment conditions

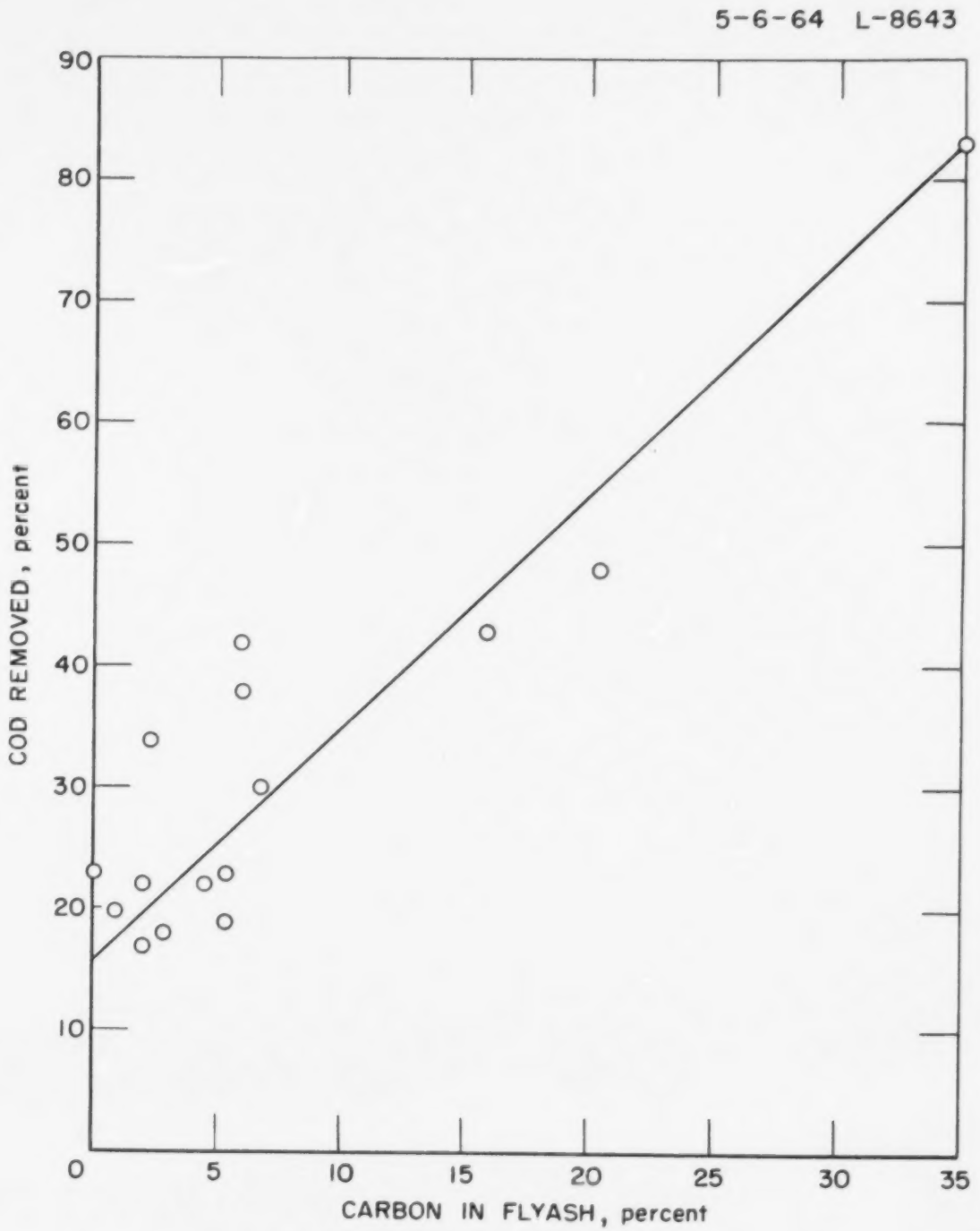


Figure 4. COD Removed in Screening Tests with Secondary Sewage Effluents and Flyashes Containing Various Amounts of Carbon.

were used: Temperatures from 400° to 900° C, pressures of atmospheric and 300 psig, and treatment gases consisting of oxygen, steam, nitrogen, and carbon dioxide in varying mixtures and concentrations. Conditions of treatment for the individual coals are given in the identification of adsorbents list, table 2.

In general the pretreated coals were only slightly better adsorbents for final waste water contaminants than were the same untreated coals. Many pretreated coals were not as efficient as some of the more effective raw coals (9A and 20A, table 4, for example), and many of the flyashes. Perhaps further tests with pretreatment of coals using different techniques and possibly the most effective raw coals would be more fruitful. The slight advantage realized with the pretreated coals tested in this screening study, however, was not sufficient to warrant continuation of this phase of the study.

Miscellaneous: Included under this category were several commercial chars and cokes, coal ashes, steel mill slag, and Michigan peat. None of these materials were efficient adsorbents for COD, the peat contributing 55 percent COD to the sewage sample as shown in table 4.

## Intensive Tests

In the intensive tests five concentrations of each selected adsorbent, 0.5, 1.0, 2.0, 4.0, and 8.0 grams per liter of final sewage effluent were stirred at 22° C for 24 hours. Two control samples were run during the same period of time; one with the adsorbent being tested and distilled water, 2.0 g/liter, to determine the amount of contaminants being contributed by the adsorbent. The other control sample was 3 liters of

stabilized filtered effluent only, no adsorbent. Since the organic contaminants contained in sewage can change during the 24-hour period of stirring due to bacterial action and/or oxidation, the control sample serves to measure the changes. The analysis of the control sample after stirring is used as the basis for computing the removal of contaminants, comparing the contaminants (COD and ABS) remaining in the sewage plus adsorbent sample to those of the control sample. In all other respects these tests were conducted similarly to the screening tests. Including activated carbon, a total of 18 materials was tested in the manner described. Two size ranges of these materials selected were tested in some cases. The materials were 1 anthracite, 1 lvb, 1 hvb, and 2 hvc bituminous coals, 2 sub-bituminous B and 1 sub-bituminous C, 1 lignite, 4 flyashes, and 1 pretreated coal, a low volatile bituminous. The results of the intensive tests are given in table 5.

Anthracite: Two different mesh sizes of the same anthracite refuse were subjected to further testing. The 200-250 mesh particles used in test 33A-2 were slightly more efficient for adsorbing COD than the 42-60 mesh particles used in test 33A-3. Removal of 5 to 53 percent of COD was obtained with the finer particles, and 2 to 36 percent with the 42-60 mesh over the range of concentrations employed. Progressively greater removal of COD was observed with increasing concentration of coal. This was not generally true with most coals as shown in subsequent results.

TABLE 5.- Results of intensive tests of adsorbents stirred with 3 liters of secondary sewage effluent at 22° C for 24 hours

| | Chemical Oxygen Demand | | Alkyl Benzene Sulfonate | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Residual, ppm | Removal, pct | Residual, ppm | Removal, pct | COD, ppm | ABS, ppm | TDS, ppm | pH | Conductivity, micromhos/cm |
| **ANTHRACITE** | | | | | | | | | |
| Test No. 33A-2 - Adsorbent - St. Nicholas anthracite rejects (200-250 mesh) | | | | | | | | | |
| Adsorbent + sewage, stirred 24 hr, g/l | | | | | | | | | |
| 0.5 | 54 | 5 | 5.5 | -0.3 | | | | | |
| 1.0 | 53 | 7 | 5.4 | - .2 | | | | | |
| 2.0 | 47 | 18 | 4.9 | 6 | | | | | |
| 4.0 | 45 | 21 | 4.1 | 21 | | | | | |
| 8.0 | 27 | 53 | 1.6 | 69 | | | | | |
| Adsorbent + distilled water, 2.0 g/l stirred 24 hr | 4 | | 0.2 | | | | | | |
| Sewage only, stirred 24 hr | 57 | | 5.2 | | | | | | |
| Stabilized, filtered sewage | | | | | 57 | 6.0 | 856 | 7.40 | 1150 |
| Test No. 33A-3 - Adsorbent - St. Nicholas anthracite rejects (42-60 mesh) | | | | | | | | | |
| Adsorbent + sewage, stirred 24 hr, g/l | | | | | | | | | |
| 0.5 | 49 | 2 | 5.9 | 0 | | | | | |
| 1.0 | 46 | 9 | 5.7 | 4 | | | | | |
| 2.0 | 43 | 14 | 4.5 | 24 | | | | | |
| 4.0 | 38 | 24 | 3.3 | 44 | | | | | |
| 8.0 | 32 | 36 | 5.5 | 7 | | | | | |
| Adsorbent + distilled water, 2.0 g/l stirred 24 hr | 17 | | 0.2 | | | | | | |
| Sewage only, stirred 24 hr | 50 | | 5.9 | | | | | | |
| Stabilized, filtered sewage | | | | | 49 | 6.4 | 776 | 7.00 | 1058 |



Continued next page

TABLE 5 .- Results of intensive tests of adsorbents stirred with 3 liters of secondary sewage effluent at 22° C for 24 hours, cont'd.

| | Chemical Oxygen Demand | | Alkyl Benzene Sulfonate | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Residual, ppm | Removal, pct | Residual, ppm | Removal, pct | COD, ppm | ABS, ppm | TDS, ppm | pH | Conductivity, micromhos/cm |
| **LOW VOLATILE BITUMINOUS COAL** | | | | | | | | | |
| **Test No. 26A-3 - Adsorbent - lvb coal (42-60 mesh)** | | | | | | | | | |
| Adsorbent + sewage, stirred 24 hr, g/l | | | | | | | | | |
| 0.5 | 56 | 0 | 5.6 | 2 | | | | | |
| 1.0 | 49 | 13 | 5.7 | 0 | | | | | |
| 2.0 | 39 | 30 | 5.8 | - 2 | | | | | |
| 4.0 | 38 | 32 | 5.6 | 2 | | | | | |
| 8.0 | 38 | 32 | 5.2 | 9 | | | | | |
| Adsorbent + distilled water, 2.0 g/l stirred 24 hr | 0 | | 0.2 | | | | | | |
| Sewage only, stirred 24 hr | *47 | | 5.7 | | | | | | |
| Stabilized, filtered sewage | | | | | 51 | 6.5 | 775 | 7.40 | 1123 |
| **Test No. 26A-4 - Adsorbent - lvb coal (200-250 mesh)** | | | | | | | | | |
| Adsorbent + sewage, stirred 24 hr, g/l | | | | | | | | | |
| 0.5 | 67 | 4 | 7.1 | 8 | | | | | |
| 1.0 | 55 | 21 | 5.6 | 27 | | | | | |
| 2.0 | 47 | 33 | 4.2 | 45 | | | | | |
| 4.0 | 55 | 21 | 6.3 | 18 | | | | | |
| 8.0 | 42 | 40 | 5.0 | 35 | | | | | |
| Adsorbent + distilled water, 2.0 g/l stirred 24 hr | 7 | | 0.2 | | | | | | |
| Sewage only, stirred 24 hr | 70 | | 7.7 | | | | | | |
| Stabilized, filtered sewage | | | | | 84 | 8.6 | 909 | 7.25 | 1218 |

*Used COD value of 56 in computing removal.

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TABLE 5.- Results of intensive tests of adsorbents stirred with 3 liters of secondary sewage effluent at 22° C for 24 hours, cont'd.

| | Chemical Oxygen Demand | | Alkyl Benzene Sulfonate | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Residual, ppm | Removal, pct | Residual, ppm | Removal, pct | COD, ppm | ABS, ppm | TDS, ppm | pH | Conductivity, micromhos/cm |
| **HIGH VOLATILE B BITUMINOUS COAL** | | | | | | | | | |
| **Test No. 3A-2 - Adsorbent - High volatile B bituminous coal (42-60 mesh)** | | | | | | | | | |
| Adsorbent + sewage, stirred 24 hr, g/l | | | | | | | | | |
| 0.5 | 52 | 8 | 6.4 | 14 | | | | | |
| 1.0 | 57 | 0 | 7.3 | 1 | | | | | |
| 2.0 | 48 | 16 | 6.0 | 19 | | | | | |
| 4.0 | 44 | 23 | 5.7 | 23 | | | | | |
| 8.0 | 55 | 4 | 7.1 | 4 | | | | | |
| Adsorbent + distilled water, 2.0 g/l stirred 24 hr | 2 | | 0.2 | | | | | | |
| Sewage only, stirred 24 hr | 57 | | 7.4 | | | | | | |
| Stabilized, filtered sewage | | | | | 59 | 8.1 | 768 | 6.85 | 1078 |
| **Test No. 3A-3 - Adsorbent - High volatile B bituminous coal (200-250 mesh)** | | | | | | | | | |
| Adsorbent + sewage, stirred 24 hr, g/l | | | | | | | | | |
| 0.5 | 47 | 4 | 5.5 | 0 | | | | | |
| 1.0 | 46 | 6 | 5.4 | 2 | | | | | |
| 2.0 | 33 | 33 | 2.9 | 47 | | | | | |
| 4.0 | 30 | 39 | 3.0 | 45 | | | | | |
| 8.0 | 36 | 27 | 4.1 | 25 | | | | | |
| Adsorbent + distilled water, 2.0 g/l stirred 24 hr | 2 | | 0.2 | | | | | | |
| Sewage only, stirred 24 hr | 49 | | 5.5 | | | | | | |
| Stabilized, filtered sewage | | | | | 51 | 6.3 | 798 | 6.45 | 979 |

Continued next page

TABLE 5.- Results of intensive tests of adsorbents stirred with 3 liters of secondary sewage effluent at 22° C for 24 hours, cont'd.

| | Chemical Oxygen Demand | | Alkyl Benzene Sulfonate | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Residual, ppm | Removal, pct | Residual, ppm | Removal, pct | COD, ppm | ABS, ppm | TDS, ppm | pH | Conductivity, micromhos/cm |
| **HIGH VOLATILE C BITUMINOUS COAL** | | | | | | | | | |
| **Test No. 10A-3 - Adsorbent - hvcb coal (42-60 mesh)** | | | | | | | | | |
| Adsorbent + sewage, stirred 24 hr, g/l | | | | | | | | | |
| 0.5 | 57 | - 6 | 5.3 | - 2 | | | | | |
| 1.0 | 58 | - 6 | 5.2 | 0 | | | | | |
| 2.0 | 53 | 2 | 5.3 | - 2 | | | | | |
| 4.0 | 49 | 9 | 4.7 | 10 | | | | | |
| 8.0 | 57 | - 6 | 4.6 | 12 | | | | | |
| Adsorbent + distilled water, 2.0 g/l stirred 24 hr | 23 | | 0.3 | | | | | | |
| Sewage only, stirred 24 hr | 54 | | 5.2 | | | | | | |
| Stabilized, filtered sewage | ---------- | | ---------- | | 65 | 6.2 | 762 | 7.60 | 1077 |
| **Test No. 20A-3 - Adsorbent - hvcb coal (42-60 mesh)** | | | | | | | | | |
| Adsorbent + sewage, stirred 24 hr, g/l | | | | | | | | | |
| 0.5 | 43 | 17 | 4.2 | 26 | | | | | |
| 1.0 | 51 | 2 | 5.3 | 8 | | | | | |
| 2.0 | 44 | 15 | 4.7 | 18 | | | | | |
| 4.0 | 30 | 42 | 2.4 | 58 | | | | | |
| 8.0 | 37 | 29 | 1.4 | 75 | | | | | |
| Adsorbent + distilled water, 2.0 g/l stirred 24 hr | 9 | | 0.1 | | | | | | |
| Sewage only, stirred 24 hr | 52 | | 5.7 | | | | | | |
| Stabilized, filtered sewage | ---------- | | ---------- | | 46 | 6.3 | 694 | 7.25 | 936 |

Continued next page

TABLE 5.- Results of intensive tests of adsorbents stirred with 3 liters of secondary sewage effluent at 22° C for 24 hours, cont'd.

| | Chemical Oxygen Demand | | Alkyl Benzene Sulfonate | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Residual, ppm | Removal, pct | Residual, ppm | Removal, pct | COD, ppm | ABS, ppm | TDS, ppm | pH | Conductivity, micromhos/cm |
| **HIGH VOLATILE C BITUMINOUS COAL** | | | | | | | | | |
| Test No. 20A-4 - Adsorbent - High volatile C bituminous coal (200-250 mesh) | | | | | | | | | |
| Adsorbent + sewage, stirred 24 hr, g/l | | | | | | | | | |
| 0.5 | 63 | 14 | 7.7 | 13 | | | | | |
| 1.0 | 35 | 52 | 2.0 | 78 | | | | | |
| 2.0 | 28 | 62 | 0.9 | 90 | | | | | |
| 4.0 | 48 | 34 | 3.2 | 64 | | | | | |
| 8.0 | 43 | 41 | 3.2 | 64 | | | | | |
| Adsorbent + distilled water, 2.0 g/l, stirred 24 hr | 6 | | 0.1 | | | | | | |
| Sewage only, stirred 24 hr | 73 | | 8.9 | | | | | | |
| Stabilized, filtered sewage | | | | | 81 | 10.6 | 885 | 7.60 | 1232 |
| **SUB-BITUMINOUS B COAL** | | | | | | | | | |
| Test No. 9A-2 - Adsorbent - Sub-bituminous B coal (42-60 mesh) | | | | | | | | | |
| Adsorbent + sewage, stirred 24 hr, g/l | | | | | | | | | |
| 0.5 | 68 | 4 | 5.9 | 0 | | | | | |
| 1.0 | 63 | 11 | 5.7 | 3 | | | | | |
| 2.0 | 38 | 46 | 2.1 | 64 | | | | | |
| 4.0 | 62 | 13 | 5.2 | 12 | | | | | |
| 8.0 | 48 | 32 | 2.4 | 59 | | | | | |
| Adsorbent + distilled water, 2.0 g/l, stirred 24 hr | 23 | | 0.2 | | | | | | |
| Sewage only stirred 24 hr | 78* | | 5.9 | | | | | | |
| Stabilized, filtered sewage | | | | | 64 | 6.5 | 825 | 6.85 | 1168 |

* Used COD value of 71 in computing removal.

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TABLE 5.- Results of intensive tests of adsorbents stirred with 3 liters of secondary sewage effluent at 22° C for 24 hours, cont'd.

| | Chemical Oxygen Demand | | Alkyl Benzene Sulfonate | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Residual, ppm | Removal, pct | Residual, ppm | Removal, pct | COD, ppm | ABS, ppm | TDS, ppm | pH | Conductivity, micromhos/cm |
| **SUB-BITUMINOUS B COAL** | | | | | | | | | |
| Test No. 9A-3 - Adsorbent - Sub-Bituminous B coal (200-250 mesh) | | | | | | | | | |
| Adsorbent + sewage, stirred 24 hr, g/l | | | | | | | | | |
| 0.5 | 36 | 28 | 3.4 | 40 | | | | | |
| 1.0 | -- | -- | --- | -- | | | | | |
| 2.0 | 49 | 2 | 4.4 | 23 | | | | | |
| 4.0 | 24 | 52 | 1.1 | 81 | | | | | |
| 8.0 | 26 | 48 | 0.9 | 84 | | | | | |
| Adsorbent + distilled water, 2.0 g/l, stirred 24 hr | 6 | | 0.2 | | | | | | |
| Sewage only, stirred 24 hr | 50 | | 5.7 | | | | | | |
| Stabilized, filtered sewage | ---------- | | ---------- | | 54 | 6.1 | 799 | 6.7 | 962 |
| Test No. 9A-4 - Adsorbent - Sub-bituminous B coal (200-250 mesh) | | | | | | | | | |
| Adsorbent + sewage, stirred 24 hr, g/l | | | | | | | | | |
| 0.5 | 92 | 11 | 6.2 | 22 | | | | | |
| 1.0 | 56 | 46 | 1.1 | 86 | | | | | |
| 2.0 | 50 | 51 | 0.7 | 91 | | | | | |
| 4.0 | 65 | 37 | 2.0 | 75 | | | | | |
| 8.0 | 55 | 47 | 0.7 | 91 | | | | | |
| Adsorbent + distilled water, 2.0 g/l, stirred 24 hr | 21 | | 0.1 | | | | | | |
| Sewage only, stirred 24 hr | 103 | | 7.9 | | | | | | |
| Stabilized, filtered sewage | ---------- | | ---------- | | 115 | 9.1 | 997 | 7.70 | 1392 |

Continued next page

TABLE 5.- Results of intensive tests of adsorbents stirred with 3 liters of secondary sewage effluent at 22° C for 24 hours, cont'd.

| | Chemical Oxygen Demand | | Alkyl Benzene Sulfonate | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Residual, ppm | Removal, pct | Residual, ppm | Removal, pct | COD, ppm | ABS, ppm | TDS, ppm | pH | Conductivity, micromhos/cm |
| **Test No. 62A-2 - Adsorbent - Sub-bituminous B coal (42-60 mesh)** | | | | | | | | | |
| Adsorbent + sewage, stirred 24 hr, g/l | | | | | | | | | |
| 0.5 | 36 | 35 | 3.7 | 24 | | | | | |
| 1.0 | 37 | 33 | 4.0 | 13 | | | | | |
| 2.0 | 36 | 35 | 4.0 | 13 | | | | | |
| 4.0 | 32 | 42 | 3.0 | 35 | | | | | |
| 8.00 | 36 | 35 | 3.1 | 33 | | | | | |
| Adsorbent + distilled water, 2.0 g/l, stirred 24 hr | 13 | | 0.5 | | | | | | |
| Sewage only, stirred 24 hr | 55 | | 4.6 | | | | | | |
| Stabilized, filtered sewage | | | | | 46 | 5.4 | 776 | 8.10 | 947 |
| **SUB-BITUMINOUS C COAL** | | | | | | | | | |
| **Test No. 6A-2 - Adsorbent sub-bituminous C coal (42-60 mesh)** | | | | | | | | | |
| Adsorbent + sewage, stirred 24 hr, g/l | | | | | | | | | |
| 0.5 | 57 | - 4 | 6.0 | 2 | | | | | |
| 1.0 | 44 | 20 | 4.2 | 31 | | | | | |
| 2.0 | 45 | 18 | 2.3 | 62 | | | | | |
| 4.0 | 50 | 9 | 4.0 | 34 | | | | | |
| 8.0 | 56 | - 2 | 4.3 | 30 | | | | | |
| Adsorbent + distilled water, 2.0 g/l, stirred 24 hr | 17 | | 0.2 | | | | | | |
| Sewage only, stirred 24 hr | 55 | | 6.1 | | | | | | |
| Stabilized, filtered sewage | | | | | 56 | 6.7 | 821 | 7.70 | 1015 |

Continued next page

TABLE 5.- Results of intensive tests of adsorbents stirred with 3 liters of secondary sewage effluent at 22° C for 24 hours, cont'd.

| | Chemical Oxygen Demand | | Alkyl Benzene Sulfonate | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Residual, ppm | Removal, pct | Residual, ppm | Removal, pct | COD, ppm | ABS, ppm | TDS, ppm | pH | Conductivity, micromhos/cm |
| **LIGNITE** | | | | | | | | | |
| Test No. 7A-2 - Adsorbent - Lignite (42-60 mesh) | | | | | | | | | |
| Adsorbent + sewage, stirred 24 hr, g/l | | | | | | | | | |
| 0.5 | 41 | 7 | 4.6 | 10 | | | | | |
| 1.0 | 46 | - 5 | 5.1 | 0 | | | | | |
| 2.0 | 43 | 2 | 3.3 | 35 | | | | | |
| 4.0 | 43 | 2 | 3.4 | 33 | | | | | |
| 8.0 | 54 | -20 | 3.5 | 31 | | | | | |
| Adsorbent + distilled water, 2.0 g/l stirred 24 hr | 17 | | 0.3 | | | | | | |
| Sewage only, stirred 24 hr | 44 | | 5.1 | | | | | | |
| Stabilized, filtered sewage | ---------- | | ---------- | | 48 | 5.6 | 663 | 6.75 | 1025 |
| **ACTIVATED CARBON** | | | | | | | | | |
| Test No. 23A-4 - Adsorbent - Activated carbon (42-60 mesh) | | | | | | | | | |
| Adsorbent + sewage, stirred 24 hr, g/l | | | | | | | | | |
| 0.5 | 15 | 74 | 0.5 | 92 | | | | | |
| 1.0 | 10 | 82 | 0.2 | 97 | | | | | |
| 2.0 | 11 | 81 | 0.4 | 94 | | | | | |
| 4.0 | 9 | 84 | 0.4 | 94 | | | | | |
| 8.0 | 3 | 95 | 0.5 | 97 | | | | | |
| Adsorbent + distilled water, 2.0 g/l, stirred 24 hr | 2 | | 0.1 | | | | | | |
| Sewage only, stirred 24 hr | 57 | | 6.2 | | | | | | |
| Stabilized, filtered sewage | ---------- | | ---------- | | 59 | 6.7 | 776 | 7.60 | 1042 |

Continued next page

TABLE 5.- Results of intensive tests of adsorbents stirred with 3 liters of secondary sewage effluent at 22° C for 24 hours, cont'd.

| | Chemical Oxygen Demand | | Alkyl Benzene Sulfonate | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Residual, ppm | Removal, pct | Residual, ppm | Removal, pct | COD, ppm | ABS, ppm | TDS, ppm | pH | Conductivity, micromhos/cm |
| **Test No. 23A-5 - Adsorbent - Activated carbon (200-250 mesh)** | | | | | | | | | |
| Adsorbent + sewage, stirred 24 hr, g/l | | | | | | | | | |
| 0.5 | 20 | 74 | 0.7 | 92 | | | | | |
| 1.0 | 7 | 91 | .3 | 97 | | | | | |
| 2.0 | 5 | 93 | .3 | 97 | | | | | |
| 4.0 | 8 | 89 | .3 | 97 | | | | | |
| 8.0 | 5 | 93 | .2 | 98 | | | | | |
| Adsorbent + distilled water, 2.0 g/l, stirred 24 hr | 2 | | .1 | | | | | | |
| Sewage only, stirred 24 hr | 76 | | 8.8 | | | | | | |
| Stabilized, filtered sewage | | | | | 86 | 9.3 | 832 | 7.75 | 1127 |
| **FLYASHES** | | | | | | | | | |
| **Test No. 34A-2 - Adsorbent - Bureau of Mines flyash (washed)** | | | | | | | | | |
| Adsorbent + sewage, stirred 24 hr, g/l | | | | | | | | | |
| 0.5 | 51 | 9 | 6.0 | 5 | | | | | |
| 1.0 | 48 | 14 | 5.4 | 14 | | | | | |
| 2.0 | 50 | 11 | 5.3 | 16 | | | | | |
| 4.0 | 43 | 23 | 4.7 | 25 | | | | | |
| 8.0 | 29 | 48 | 3.2 | 49 | | | | | |
| Adsorbent + distilled water, 2.0 g/l, stirred 24 hr | 1 | | 0.3 | | | | | | |
| Sewage only, stirred 24 hr | 56 | | 6.3 | | | | | | |
| Stabilized, filtered sewage | | | | | 52 | 7.0 | 848 | 6.90 | 1095 |

Continued next page

TABLE 5.- Results of intensive tests of adsorbents stirred with 3 liters of secondary sewage effluent at 22° C for 24 hours, cont'd

| | Chemical Oxygen Demand | | Alkyl Benzene Sulfonate | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Residual, ppm | Removal, pct | Residual, ppm | Removal, pct | COD, ppm | ABS, ppm | TDS, ppm | pH | Conductivity, micromhos/cm |
| Test No. 34A-4 - Adsorbent - Bureau of Mines flyash (35.3 pct C) | | | | | | | | | |
| Adsorbent + sewage, stirred 24 hr, g/l | | | | | | | | | |
| 0.5 | 61 | 21 | 7.2 | 13 | | | | | |
| 1.0 | 54 | 30 | 5.8 | 30 | | | | | |
| 2.0 | 38 | 51 | 2.3 | 72 | | | | | |
| 4.0 | 54 | 30 | 4.2 | 49 | | | | | |
| 8.0 | 27 | 65 | 1.1 | 87 | | | | | |
| Adsorbent + distilled water, 2.0 g/l, stirred 24 hr | 2 | | 0.3 | | | | | | |
| Sewage only, stirred 24 hr | 77 | | 8.3 | | | | | | |
| Stabilized, filtered sewage | ---------- | | ---------- | | 87 | 9.1 | 818 | 7.50 | 1181 |
| Test No. 35A-2 - Adsorbent - Mitchell Power Station flyash (6.0 pct C) | | | | | | | | | |
| Adsorbent + sewage, stirred 24 hr, g/l | | | | | | | | | |
| 0.5 | 29 | 19 | 2.9 | -12 | | | | | |
| 1.0 | 28 | 22 | 2.5 | 4 | | | | | |
| 2.0 | 27 | 25 | 1.8 | 31 | | | | | |
| 4.0 | 22 | 39 | 1.0 | 61 | | | | | |
| 8.0 | 16 | 56 | 0.6 | 77 | | | | | |
| Adsorbent + distilled water, 2.0 g/l, stirred 24 hr | 3 | | 0.3 | | | | | | |
| Sewage only, stirred 24 hr | 36 | | 2.6 | | | | | | |
| Stabilized, filtered sewage | ---------- | | ---------- | | 45 | 3.0 | 736 | 8.00 | 1174 |

Continued next page

TABLE 5.- Results of intensive tests of adsorbents stirred with 3 liters of secondary sewage effluents at 22° C for 24 hours, cont'd.

| | Chemical Oxygen Demand | | Alkyl Benzene Sulfonate | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Residual, ppm | Removal, pct | Residual, ppm | Removal, pct | COD, ppm | ABS, ppm | TDS, ppm | pH | Conductivity, micromhos/cm |
| Test No. 43A-2 - Adsorbent - Duquesne Light Co., Floreffe, Pa., flyash (6.0 pct C) | | | | | | | | | |
| Adsorbent + sewage, stirred 24 hr, g/l | | | | | | | | | |
| 0.5 | 49 | 20 | 6.6 | 4 | | | | | |
| 1.0 | 51 | 16 | 6.4 | 7 | | | | | |
| 2.0 | 50 | 18 | 5.9 | 15 | | | | | |
| 4.0 | 40 | 34 | 5.2 | 25 | | | | | |
| 8.0 | 28 | 54 | 2.9 | 58 | | | | | |
| Adsorbent + distilled water, 2.0 g/l, stirred 24 hr | 19 | | 0.2 | | | | | | |
| Sewage only, stirred 24 hr | 61 | | 6.9 | | | | | | |
| Stabilized, filtered sewage | ---------- | | ---------- | | 60 | 7.7 | 897 | 7.50 | 1229 |
| Test No. 54A-2 - Adsorbent - Minn. Power and Light Co. flyash (20.4 pct C) | | | | | | | | | |
| Adsorbent + sewage, stirred 24 hr, g/l | | | | | | | | | |
| 0.5 | 57 | 10 | 7.2 | - 1 | | | | | |
| 1.0 | 56 | 11 | 6.8 | 4 | | | | | |
| 2.0 | 48 | 24 | 5.8 | 18 | | | | | |
| 4.0 | 42 | 33 | 4.9 | 31 | | | | | |
| 8.0 | 29 | 54 | 3.2 | 55 | | | | | |
| Adsorbent + distilled water, 2.0 g/l, stirred 24 hr | 5 | | 0.3 | | | | | | |
| Sewage only, stirred 24 hr | 63 | | 7.1 | | | | | | |
| Stabilized, filtered sewage | ---------- | | ---------- | | 74 | 7.5 | 700 | 7.10 | 937 |

Continued next page

TABLE 5.- Results of intensive tests of adsorbents stirred with 3 liters of secondary sewage effluents at 22° C for 24 hours, cont'd.

| | Chemical Oxygen Demand | | Alkyl Benzene Sulfonate | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Residual, ppm | Removal, pct | Residual, ppm | Removal, pct | COD, ppm | ABS, ppm | TDS, ppm | pH | Conductivity, micromhos/cm |
| Adsorbent ÷ sewage, stirred 24 hr, g/l | Test No. 60A-2 - Adsorbent - Philadelphia Electric Co. flyash (15.8 pct C) | | | | | | | | |
| 0.5 | 53 | 15 | 6.3 | 7 | | | | | |
| 1.0 | 48 | 23 | 5.8 | 15 | | | | | |
| 2.0 | 45 | 27 | 4.8 | 19 | | | | | |
| 4.0 | 32 | 48 | 3.4 | 50 | | | | | |
| 8.0 | 21 | 66 | 1.6 | 76 | | | | | |
| Adsorbent ÷ distilled water, 2.0 g/l, stirred 24 hr | 10 | | 0.3 | | | | | | |
| Sewage only, stirred 24 hr | 62 | | 6.8 | | | | | | |
| Stabilized, filtered sewage | ---------- | | ---------- | | 65 | 6.9 | 676 | 7.20 | 854 |
| | Test No. 30A-2 - Adsorbent - Pretreated lvb coal (42-60 mesh) | | | | | | | | |
| Adsorbent ÷ sewage, stirred 24 hr, g/l | | | | | | | | | |
| 0.5 | 52 | 10 | 7.1 | 0 | | | | | |
| 1.0 | 57 | 3 | 7.1 | 0 | | | | | |
| 2.0 | 46 | 28 | 5.8 | 18 | | | | | |
| 4.0 | 50 | 15 | 6.7 | 6 | | | | | |
| 8.0 | 37 | 37 | 4.2 | 41 | | | | | |
| Adsorbent ÷ distilled water, 2.0 g/l, stirred 24 hr | 4 | | 0.2 | | | | | | |
| Sewage only, stirred 24 hr | 59 | | 7.1 | | | | | | |
| Stabilized, filtered sewage | ---------- | | ---------- | | 71 | 8.1 | 769 | 7.70 | 1180 |

Low volatile bituminous: Two particle sizes of the selected lvb coal were tested, 42-60 mesh in test 26A-3, and 200-250 in test 26A-4. Again the finer mesh size (26A-4) was slightly better but much less of an improvement than might be expected based on the relative surface areas. At concentrations above 2 g/liter there was virtually no increase in removal of contaminants.

High volatile bituminous:

High volatile B bituminous: In test 3A-2 with 42-60 mesh the removal was poor. Test 3A-3 with 200-250 mesh sizes of the same hvbb coal showed some improvement with the removal of COD reaching a maximum of about 35 percent.

High volatile C bituminous: The hvcb coal used in test 10A-3 was a very inefficient adsorbent, actually contributing COD with three of the adsorbent concentrations. In the screening test with this same coal (test 10A-1, table 4), 33 percent COD removal had been obtained with 3 g/liter concentration. Whereas 3 g/liter of the coal in distilled water had contributed only 3 ppm COD in the screening test, 23 ppm COD resulted in the blank test from 2 g/liter in distilled water. The much higher COD contributed by the coal in the extensive test accounts for its poor adsorption results. This factor of possible contribution of contaminants by the coal points out the need for careful selectivity, and also emphasizes the difference between coal and usual types of adsorbents which can only remove and not add to the water.

Tests 20A-3 and 20A-4 employed 42-60 and 200-250 mesh sizes of a second hvcb coal. The finer mesh size is again the more efficient adsorbent for COD and especially ABS, although not in all comparable adsorbent concentrations. Both the COD and ABS of the stirred sewage were somewhat higher in test 20A-4 than in 20A-3, being 73 and 8.9 compared to 52 and 5.7 ppm, respectively. Thus the superiority of the 200-250 mesh coal as an adsorbent over 42-60 mesh is even greater due to the higher loading of the finer mesh size.

Sub-bituminous coal

Sub-bituminous B coal: Three samples of sub-bituminous B coal 9A were extensively tested, one 42-60 mesh sample and two 200-250 mesh samples. COD removals with the different mesh sizes were fairly similar although the ABS removed was greater with the 42-60 mesh size sample. Comparisons with contaminant removals obtained in the screening test with this coal were good.

The sub-bituminous coal used in test 62A-2 removed about 35 percent COD at all adsorbent concentrations. This was not the usual pattern of results with coals. Generally the removal of COD increased with adsorbent concentration to a maximum (generally at 2.0 or 4.0 g/liter adsorbent concentration), and then dropped off at the high concentrations. But in this case even the 0.5 g/liter concentration removed 35 percent of the COD and 24 percent of the ABS present, approximately the same amount as removed by the 8.0 g/liter concentration.

Sub-bituminous C coal: The sub-bituminous C coal tested (6A-2) was a poor adsorbent at all adsorbent concentrations, contributing COD at the high and low adsorbent concentrations. This coal had shown poor COD removal in the screening test (test 6A-1) also, but was chosen to represent this rank of coal. A high amount of COD (17 ppm) was contributed by 2 g/liter dosage of the coal in distilled water.

Lignite: Lignite in an intensive test (7A-2) was a poor adsorbent, removing either small amounts of COD or contributing to the COD of the sewage-lignite mixture. These results disagree with those of the screening test 7A-1 where 33 percent COD had been removed. The intensive test is more reliable as it is based on results of five adsorbent concentrations compared to the single dosage of the screening test. The high amount of COD contributed by the lignite in both tests, 17 ppm, would eliminate it as a desirable adsorbent.

Activated carbon: As reference material two sizes of commercial activated carbon, 42-60 and 200-250 mesh, were tested in 23A-4 and 23A-5, respectively. The finer mesh carbon was a slightly better adsorbent for COD although the range of removal in both cases was considerably above most coals, about 74-94 percent. Since the sewage used in test 23A-5 contained higher COD and ABS contents than that used in test 23A-4, the total pickup of contaminants per weight of adsorbent is greater with the 200-250 mesh size carbon. From 92 to 97 percent of the ABS was removed with both mesh sizes.

The uniformity of results obtained with activated carbon indicates that the carbon samples were much more homogeneous than were the coal samples.

Increasing the carbon dosage beyond 1.0 g/liter had little effect on the contaminant removals obtained with the 200-250 mesh carbon, and only a slight increase with the 42-60 mesh size.

Flyashes: Six flyashes were intensively tested, four from commercial powerplants and two samples of flyash from the Bureau of Mines boiler house. The Bureau flyash used in test 34A-2 was washed with distilled water, thus removing the light particles that floated. All other flyashes were tested as received except for drying.

All the flyashes were fairly good adsorbents, removing from 48 to 66 percent COD at the maximum adsorbent concentration of 8.0 g/liter, and from 49 to 87 percent of the ABS. Even at the lowest adsorbent concentration tested, 0.5 g/liter, from 9 to 21 percent COD was removed. In general, increased contaminant removal was achieved with increased adsorbent concentration. In this respect the test results with flyash were much more uniform than those with coals. Virtually no COD was contributed by the flyashes, which behaved similarly to the activated carbon in this respect.

The flyashes settled out as readily as coal after stirring ceased. Generally within about 30 minutes, settling of the bulk of the solids was complete except for any very fine particles that remained in suspension. The wetting ability of the ABS in the sewage aided the settling out of the adsorbents as noted by the difference in settling abilities between the adsorbents mixed with sewage as compared to those stirred with distilled water.

Pretreated coal: The lvb pretreated coal intensively tested in test 30A-2 was a comparatively inefficient adsorbent for both COD and ABS. At an 8.0 g/liter adsorbent concentration only 37 percent of the COD and 41 percent of the ABS were removed with much lower removals obtained at lower adsorbent concentrations.

## Extended Tests

Because the intensive tests with the coals showed that there was not a direct relationship between the effectiveness of removal of contaminants and concentration of the adsorbent, the results did not permit a rational extrapolation of the maximum pickup of contaminant by the coal. To provide such information, a sample of hvc bituminous coal, one of the more effective materials, underwent tests in which it was subject to re-use to determine how rapidly it lost its effectiveness as an adsorbent.

### Two-Stage

In order to essentially simulate in batch tests the flow pattern encountered in a countercurrent flow column type of operation, two two-stage tests were made, the results of which are listed in table 6. A normal screening type test was made with 3 g/liter of hvcb coal (42-60 mesh) stirred with 3 liters of stabilized, filtered secondary effluent. After 24 hours of contact, liquid samples were removed for analysis (designated "first stage" in table 6). The coal and sewage were then separated by decanting and filtering (through Whatman No. 5 paper). To the filtered sewage, 3 grams per liter of fresh hvcb coal was added and stirring continued for another 24 hours. Three liters of fresh sewage was added to the separated, used coal and stirring

TABLE 6.- Results of 2-stage tests with 3 grams per liter dosages of a hvcb coal (42-60 mesh) stirred at 22° C for 24-hour periods with secondary sewage effluent

| | Test No. 20A-5 | | | Test No. 20A-6 | | |
|---|---|---|---|---|---|---|
| | First stage | Second stage | | First stage | Second stage | |
| | | Recovered coal + fresh sewage (3 l.) | Recovered sewage + fresh coal (9.0 g.) | | Recovered coal + fresh sewage (3 l.) | Recovered sewage + fresh coal (3 g./l.) |
| **Chemical Oxygen Demand** | | | | | | |
| Sewage only | | | | | | |
| Stabilized, filtered, ppm | 71 | -- | -- | 65 | -- | -- |
| Stirred 24 hours, ppm | 65 | 63 | 47 | 55 | 53 | 42 |
| Distilled water + adsorbent, stirred 24 hours, ppm | 11 | -- | 9 | 9 | -- | -- |
| Sewage + adsorbent, stirred 24 hours, ppm | 47 | 46 | 23 | 42 | 43 | 27 |
| Removal, 24 hours, percent | 28 | 27 | 51 | 21 | 19 | 36 |
| Removal, overall, percent | | | 65 | | | 49 |
| **Alkyl Benzene Sulfonate** | | | | | | |
| Sewage only | | | | | | |
| Stabilized, filtered, ppm | 6.6 | -- | -- | 6.0 | -- | -- |
| Stirred 24 hours, ppm | 5.7 | 5.5 | 2.4 | 5.2 | 5.2 | 3.0 |
| Distilled water + adsorbent, stirred 24 hours, ppm | 0.3 | -- | 0.3 | 0.3 | -- | -- |
| Sewage + adsorbent, stirred 24 hours, ppm | 2.4 | 3.4 | 0.8 | 3.0 | 2.6 | 1.0 |
| Removal, 24 hours, percent | 58 | 38 | 67 | 42 | 50 | 67 |
| Removal, overall, percent | | | 36 | | | 81 |
| **Stabilized filtered sewage** | | | | | | |
| Total dissolved solids, ppm | 766 | 766 | | 762 | 762 | |
| pH | 7.50 | 7.50 | | 7.60 | 7.60 | |
| Conductivity, micromhos/cm | 1053 | 1053 | | 1077 | 1077 | |

continued for 24 hours. At the end of this period COD and ABS determinations were made on the contents of both test flasks (designated "second stage" in table 6).

In test 20A-5, 28 percent COD removal was obtained in the first stage; this same coal, when filtered and contacted with 3 liters of fresh sewage, removed 27 percent of the COD, practically the same amount as in the first stage. The ABS removal obtained in the first stage was 58 percent compared to 38 percent in the second stage.

When the recovered sewage from the first stage was contacted with fresh coal (9.0 grams), the COD dropped from 47 to 23 ppm, a 51 percent removal; the ABS in this same sewage dropped from 2.4 to 0.8 ppm, or a 67 percent removal. In both cases the percentage removals obtained were greater than initially. In two stages of treatment the COD of the original sewage was lowered from 65 to 23 ppm (65 percent removal), and the ABS from 5.7 to 0.8 ppm (86 percent removal).

Test 20A-6 was a duplicate of test 20A-5 except that a different batch of fresh, secondary effluent was used, and in dosing the recovered sewage (second stage) with fresh coal, allowance was made for the sewage removed for analytical purposes in the first stage. The coal dosage used was 3 grams per liter, while in test 20A-5, 9.0 grams of fresh coal was used, so that the concentration was somewhat greater than 3 grams per liter in test 20A-5.

The results of test 20A-6 are similar to those of 20A-5: The used coal picked up about the same amount of contaminants in the second stage as it did in the first stage as fresh coal, and the treated sewage from

the first stage was purified even more percentage-wise in the second stage than in the first stage. The overall COD removal obtained by 2-step treatment was 49 percent, and the ABS removal was 81 percent.

Multi-stage

To further evaluate the coal, two 10-stage tests were made. A sample of the same hvcb coal used in the two-stage tests and activated carbon were thus tested.

In table 7 the results are given of an extended repetitive test in which the original 9.0 grams of hvcb coal (42-60 mesh) was contacted with fresh sewage every 24 hours until the coal would adsorb no additional COD. After each 24-hour contact period the coal and sewage were separated by filtering through No. 5 Whatman paper. The separated sewage was either discarded or dosed with fresh coal for the next part of the test. The recovered coal to be further tested was removed from the wet filter paper without drying and was placed in a test flask containing fresh sewage. (This series of tests was operated similarly to those discussed above and illustrated in table 6, except that the time has been extended.) The sewage from the initial contact period (first stage) was successively exposed to fresh coal samples (3 g/liter) for 24-hour periods until no further COD could be removed.

The original sewage was contacted with fresh coal a total of four times with the lowest COD and ABS levels reached being 21 ppm and 0.4 ppm, respectively. Actually no additional removal was obtained after two contacts. With a COD value of 54 ppm and ABS of 4.7 ppm initially, the percentage removal of COD obtained was 61 and of ABS 92. After each

TABLE 7.- Results of multi-stage tests with 3 g/liter dosages of a hvcb coal (42-60 mesh) stirred at 22° C for 24-hour periods with secondary sewage effluent

| | Test No. 20A-7 | | | | | | |
|---|---|---|---|---|---|---|---|
| | First stage | Second stage | | Third stage | | Fourth stage | |
| | | Recovered coal + fresh sewage (3 l.) | Recovered sewage + fresh coal (8.7 g) | Recovered coal + fresh sewage (3 l.) | Recovered sewage + fresh coal (8.4 g) | Recovered coal + fresh sewage (3 l.) | Recovered sewage + fresh coal (8.1 g) |
| Chemical Oxygen Demand | | | | | | | |
| Sewage only | | | | | | | |
| Stabilized, filtered, ppm | 65 | -- | -- | -- | -- | -- | -- |
| Stirred 24 hours, ppm | 54 | 51 | -- | 52 | -- | 55 | -- |
| Distilled water + adsorbent, stirred 24 hours, ppm | 12 | -- | -- | -- | -- | -- | -- |
| Sewage + adsorbent, stirred 24 hours, ppm | 33 | 28 | 22 | 32 | 28 | 40 | 21 |
| Removal, 24 hours, pct | 39 | 45 | 33 | 38 | -21 | 27 | 25 |
| Alkyl Benzene Sulfonate | | | | | | | |
| Sewage only | | | | | | | |
| Stabilized, filtered, ppm | 5.8 | -- | -- | -- | -- | -- | -- |
| Stirred 24 hours, ppm | 4.7 | 4.6 | -- | 4.7 | -- | 4.9 | -- |
| Distilled water + adsorbent, stirred 24 hours, ppm | 0.3 | -- | -- | -- | -- | -- | -- |
| Sewage + adsorbent, stirred 24 hours, ppm | 0.8 | 1.8 | 0.4 | 2.5 | 0.4 | 3.2 | 0.5 |
| Removal, 24 hours, pct | 83 | 61 | 50 | 47 | 0 | 35 | -25 |
| Stabilized filtered sewage | | | | | | | |
| Total dissolved solids, ppm | 688 | 688 | | 688 | | 688 | |
| pH | 8.00 | 8.00 | | 8.00 | | 8.00 | |
| Conductivity, micromhos/cm | 1005 | 1005 | | 1005 | | 1005 | |

Continued next page

TABLE 7.- Results of multi-stage tests with 3 g/liter dosages of a hvcb coal (42-60 mesh) stirred at 22° C for 24-hour periods with secondary sewage effluent, cont'd.

| | Test No. 20A-7 | | | | | | |
|---|---|---|---|---|---|---|---|
| | Fifth stage | | Sixth stage | Seventh stage | Eighth stage | Ninth stage | Tenth stage |
| | Recovered coal ÷ fresh sewage (3 l.) | Recovered sewage + fresh coal | Recovered coal ÷ fresh sewage (3 l.) | | | | |
| **Chemical Oxygen Demand** | | | | | | | |
| Sewage only | | | | | | | |
| Stabilized, filtered, ppm | -- | Dis- | 54 | -- | -- | 65 | -- |
| Stirred 24 hours, ppm | 47 | continued | 48 | 50 | 49 | 51 | 51 |
| Distilled water + adsorbent, stirred 24 hours, ppm | -- | | -- | -- | -- | | |
| Sewage + adsorbent, stirred 24 hours, ppm | 38 | | 39 | 36 | 45 | 55 | 42 |
| Removal, 24 hours, percent | 19 | | 19 | 28 | 8 | -8 | 18 |
| **Alkyl Benzene Sulfonate** | | | | | | | |
| Sewage only | | | | | | | |
| Stabilized, filtered, ppm | -- | | 4.3 | -- | -- | 5.5 | -- |
| Stirred 24 hours, ppm | 4.8 | | 3.9 | 3.8 | 3.8 | 4.7 | 4.9 |
| Distilled water + adsorbent, stirred 24 hours, ppm | -- | | -- | -- | -- | -- | -- |
| Sewage + adsorbent, stirred 24 hours, ppm | 4.4 | | 3.9 | 3.8 | 3.6 | 4.2 | 4.4 |
| Removal, 24 hours, percent | 8 | | 0 | 0 | 5 | 11 | 10 |
| **Stabilized filtered sewage** | | | | | | | |
| Total dissolved solids, ppm | 688 | | 426 | 426 | 426 | 710 | 710 |
| pH | 8.00 | | 7.30 | 7.30 | 7.30 | 7.70 | 7.70 |
| Conductivity, micromhos/cm | 1005 | | 633 | 633 | 633 | 935 | 935 |

separation of the adsorbent from the sewage, a 100-ml sewage sample was removed for analytical determinations; thus the total sewage volume was lessened and the amount of fresh coal added was reduced by 0.3 gram with each contact so as to maintain a 3 g/liter adsorbent dosage.

The initial 9.0 grams of coal was contacted with fresh sewage a total of 10 times with definite COD removal obtained on eight contacts; the ninth contact added COD to the sewage and the tenth again removed COD. During every contact period a control sample of sewage alone was also stirred at 22° C to be used as the base for computing both COD and ABS removals. Similar repetitive tests were made using activated carbon as adsorbent, as described subsequently.

A plot of the weight of COD and ABS removed per gram of adsorbent versus time for this test and a similar test with activated carbon is shown in figure 5. The coal adsorbed a total of about 4 percent of its weight of COD and 0.4 percent of its weight of ABS, while activated carbon in similar tests adsorbed about 10 percent of its weight of COD and 1.2 percent of its weight of ABS in ten 24-hour contact periods. The carbon was not yet saturated with contaminants as indicated by the slopes of its curves, but the coal removed little contaminants after the sixth or seventh contact periods.

The tests were terminated after 10 contact periods due to the difficulty of filtering. Considerable attrition of the original 42-60 mesh size adsorbents occurred and adsorbent loss was increasing because of the fine particles becoming imbedded in the filter paper, and because of ordinary handling losses.

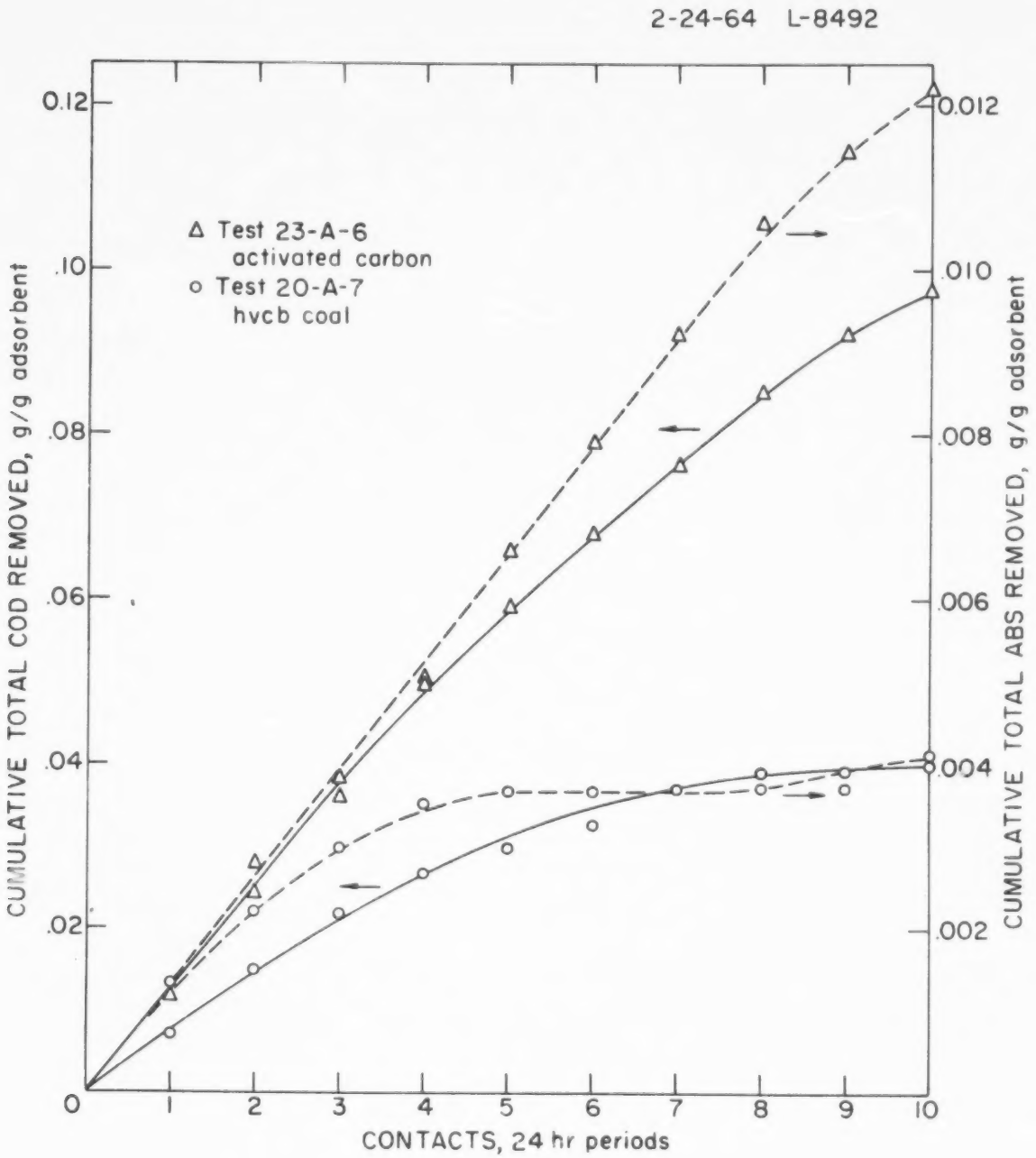


Figure 5. COD and ABS Removed by Activated Carbon and a High Volatile C Bituminous Coal.

Table 8 lists the results of a repetitive test with activated carbon similar to that with coal listed in table 7. The COD content of the original sewage was lowered from 48 to 4 ppm and the ABS from 3.9 to 0.1 ppm, equivalent to 92- and 97-percent removals, respectively.

Comparing the removals obtained with hvcb coal after two stages at the same operating conditions of excess fresh adsorbent (59 percent COD and 92 percent ABS removed) and those obtained with activated carbon (92 percent COD and 97 percent ABS removed), the coal is 64 percent as effective for COD removal and 95 percent as effective for ABS removal as activated carbon. These tests indicate the presence of some easily and quickly adsorbable contaminants in the domestic sewage treated. Also present are some contaminants very difficult to adsorb which would require much longer contact times for removal.

Comparison of the total contaminants removed by the original samples of coal and carbon cannot be made since the carbon was not saturated after 10 cycles of operation, but after 10 cycles the carbon had removed about three times the total weight of contaminants removed by coal. The decreasing slope of the curve of COD removal with time (figure 5) for the activated carbon indicates that the incremental adsorption per cycle is decreasing and that the curve will flatten as did that for the coal. By extrapolation an estimated saturation value of about 14-17 percent will be obtained in about 20-25 repetitive tests. Thus the indicated ultimate capacity of the hvcb coal is about 25 percent that of the carbon.

TABLE 8.- Results of multi-stage tests with 3 g/liter dosages of activated carbon (42-60 mesh) stirred at 22° C for 24-hour periods with secondary sewage effluent

| | Test No. 23A-6 | | | | | | |
|---|---|---|---|---|---|---|---|
| | First stage | Second stage | | Third stage | | Fourth stage | |
| | | Recovered carbon + fresh sewage (3 l.) | Recovered sewage + fresh carbon (8.7 g) | Recovered carbon + fresh sewage (3 l.) | Recovered sewage + fresh carbon (8.4 g) | Recovered carbon + fresh sewage (3 l.) | Recovered sewage + fresh carbon |
| Chemical Oxygen Demand | | | | | | | |
| Sewage only | | | | | | | |
| Stabilized, filtered, ppm | 54 | -- | -- | -- | -- | 65 | Dis- |
| Stirred 24 hours, ppm | 48 | 50 | -- | 49 | -- | 51 | continued |
| Distilled water + adsorbent, stirred 24 hours, ppm | 3 | -- | -- | -- | -- | -- | |
| Sewage + adsorbent, stirred 24 hours, ppm | 8 | 7 | 4 | 17 | 6 | 16 | |
| Removal, 24 hours, percent | 83 | 86 | 50 | 65 | - 50 | 69 | |
| Alkyl Benzene Sulfonate | | | | | | | |
| Sewage only | | | | | | | |
| Stabilized, filtered, ppm | 4.3 | -- | -- | -- | -- | 5.5 | |
| Stirred 24 hours, ppm | 3.9 | 3.8 | -- | 3.8 | -- | 4.7 | |
| Distilled water + adsorbent, stirred 24 hours, ppm | 0.3 | -- | -- | -- | -- | -- | |
| Sewage + adsorbent, stirred 24 hours, ppm | 0.2 | 0.2 | 0.1 | 0.3 | 0.2 | 0.3 | |
| Removal, 24 hours, percent | 95 | 95 | 50 | 92 | -50 | 94 | |
| Stabilized filtered sewage | | | | | | | |
| Total dissolved solids, ppm | 426 | 426 | | 426 | | 710 | |
| pH | 7.30 | 7.30 | | 7.30 | | 7.70 | |
| Conductivity, micromhos/cm | 633 | 633 | | 633 | | 935 | |

Continued next page

TABLE 8.- Results of multi-stage tests with 3 g/liter dosages of activated carbon (42-60 mesh) stirred at 22° C for 24-hour periods with secondary sewage effluent, cont'd.

| | Test No. 23A-6 | | | | | |
|---|---|---|---|---|---|---|
| | Fifth stage | Sixth stage | Seventh stage | Eighth stage | Ninth stage | Tenth stage |
| | Recovered carbon plus fresh sewage (3 l.) | | | | | |
| **Chemical Oxygen Demand** | | | | | | |
| Sewage only | | | | | | |
| Stabilized, filtered, ppm | -- | 51 | -- | -- | 42 | -- |
| Stirred 24 hours, ppm | 51 | 43 | 38 | 44 | 35 | 36 |
| Distilled water + adsorbent, stirred 24 hours, ppm | -- | -- | -- | -- | -- | -- |
| Sewage + adsorbent, stirred 24 hours, ppm | 25 | 16 | 14 | 16 | 14 | 20 |
| Removal, 24 hours, percent | 51 | 63 | 63 | 64 | 60 | 44 |
| **Alkyl Benzene Sulfonate** | | | | | | |
| Sewage only | | | | | | |
| Stabilized, filtered, ppm | -- | 5.0 | -- | -- | 3.5 | -- |
| Stirred 24 hours, ppm | 4.9 | 4.3 | 4.5 | 4.4 | 2.9 | 2.6 |
| Distilled water + adsorbent, stirred 24 hours, ppm | -- | -- | -- | -- | -- | -- |
| Sewage + adsorbent, stirred 24 hours, ppm | 0.4 | 0.3 | 0.3 | 0.4 | 0.3 | 0.3 |
| Removal, 24 hours, percent | 92 | 93 | 93 | 91 | 90 | 88 |
| **Stabilized filtered sewage** | | | | | | |
| Total dissolved solids, ppm | 710 | 680 | 680 | 680 | 646 | 646 |
| pH | 7.70 | 8.20 | 8.20 | 8.20 | 7.80 | 7.80 |
| Conductivity, micromhos/cm | 935 | 811 | 811 | 811 | 898 | 898 |

It is realized that the contact times used in these batch tests are much greater than would be used in commercial practice, but the ultimate adsorption capacities of an adsorbent can be determined in this manner. In actual practice with countercurrent flow of adsorbent and sewage the adsorbent would be continuously contacted with "fresh" sewage, so that it would become saturated with contaminants much more rapidly.

## CORRELATION OF DATA

### Rank and Composition of Coal

One of the original aims of the study was to determine whether the coal rank was related to the adsorption characteristics. The data obtained conclusively eliminate the rank of a coal as a factor for the adsorption of waste water refractory contaminants. One coal of a certain rank can be a good adsorbent, while another of the same rank is very ineffective. For example, in intensive tests (Table 5, 20A-3, 20A-4, etc.) with hvcb coals, coal 20A was one of the better adsorbents, while 10A was inefficient. The same is true in the sub-bituminous rank in the screening tests (table 4); the coal in test 9A-1 removed 44 percent of the COD while those of 19A-1 and 62A-1, although of the same rank, removed only 18 and 16 percent COD, respectively. Generally those coals contributing the higher amounts of COD when mixed with distilled water were the poorer adsorbents, and conversely those contributing lower amounts of COD were among the better adsorbents. There were exceptions to both cases, however.

Attempts were made to correlate COD and ABS removals with volatile matter, ash content, and carbon content of the coals as shown in figures 6, 7, and 8 respectively. Proximate coal analyses values were plotted with COD and ABS removals obtained in screening tests with final effluent and 3 g/liter adsorbent dosages. In those cases where an individual coal contributed COD or ABS overall, the removals of those components are plotted as zero. Each test result is labeled with the rank of coal used, thus also illustrating the independence of removal with rank. The efficiency of adsorption of COD and ABS could not be related to any of the three components; both high- and low-contaminant removals were obtained with coals of high and low volatile matter, ash and carbon contents as shown by the unoriented scattering of points (figures 6, 7, and 8).

## Isotherm Plots for COD

The intensive tests employing five concentrations of adsorbent over a wide range of 0.5 to 8.0 g/liter were designed to provide data for adsorption isotherms of the materials under test. From the isotherms the effectiveness of the adsorbents could be readily compared and the ultimate capacity of the adsorbents estimated. An adsorption isotherm for activated carbon was available in the literature.[7/]

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7/ Work cited in footnote 1, page 5.

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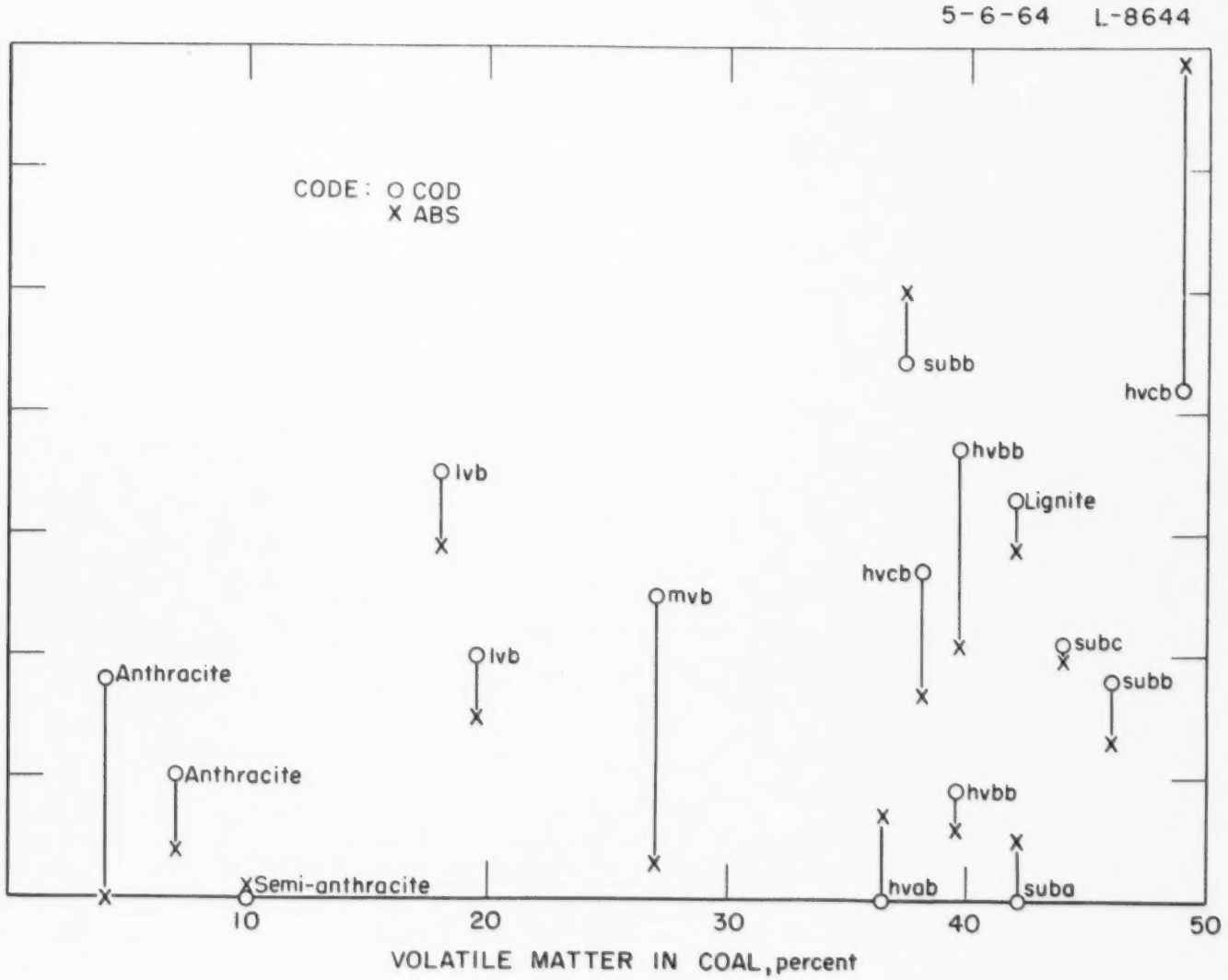
Adsorption isotherms were plotted for COD removal using data of this study from two 24-hour intensive tests with activated carbon (23A-4 and 23A-5). The weights of COD adsorbed per unit weight of the five carbon dosages used were plotted against residual filtrate concentration

Figure 6. Removal of COD and ABS from Final Effluent by Coals of Various Volatile Matter Contents.



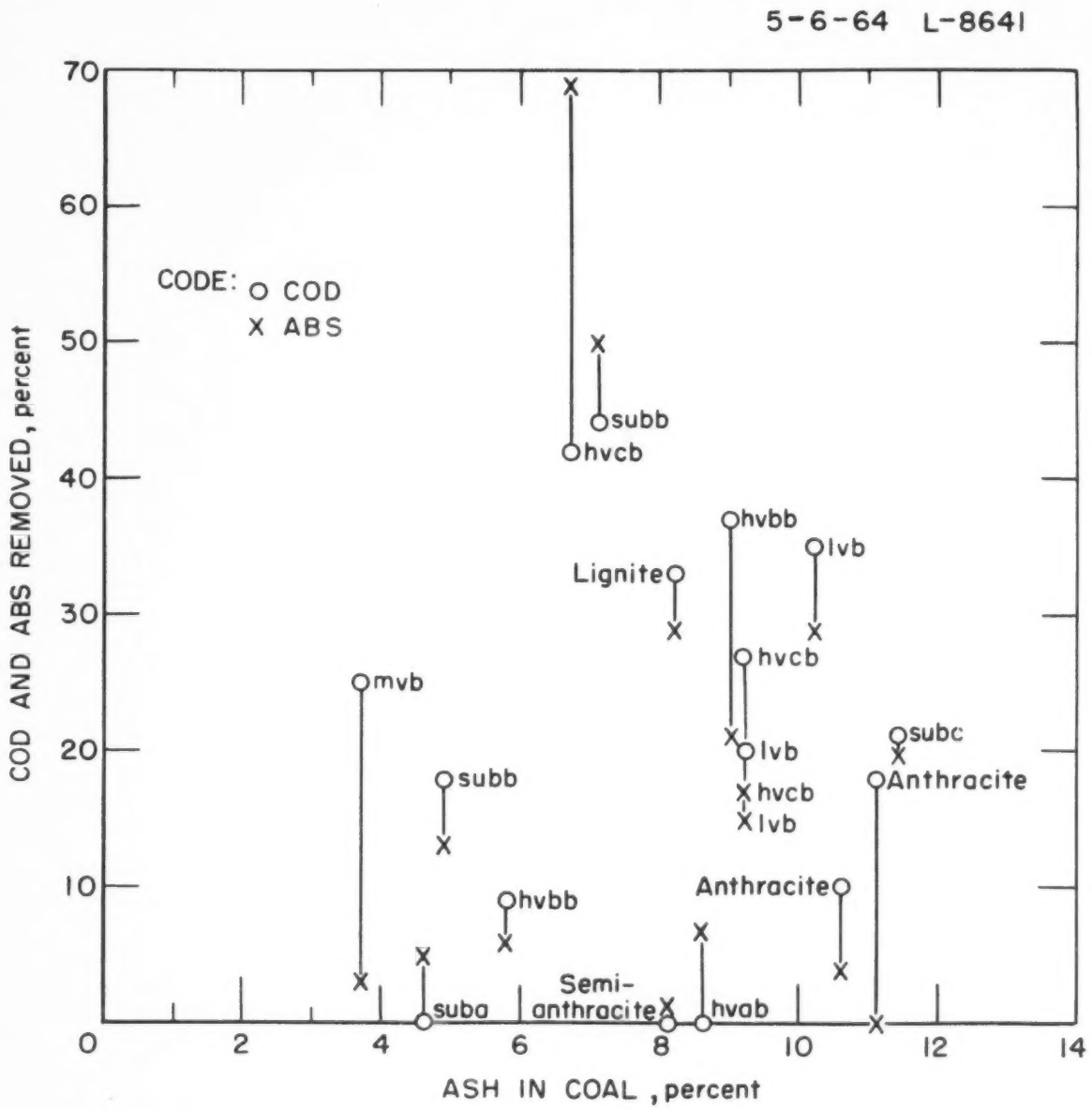
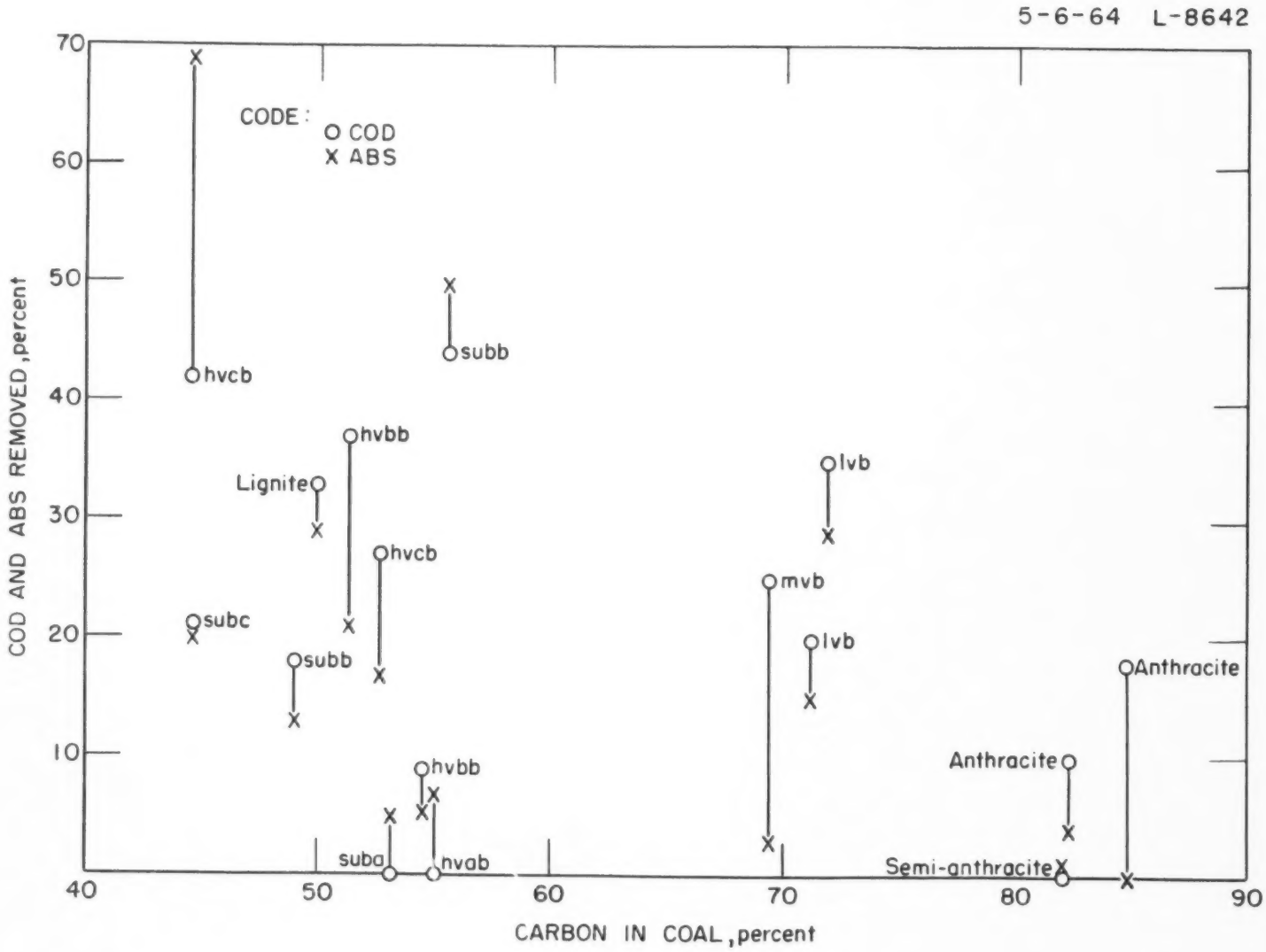



Figure 7. Removal of COD and ABS from Final Effluent by Coals of Various Ash Contents.

Figure 8. Removal of COD and ABS from Final Effluent by Coals of Various Carbon Contents.



using logarithmic coordinates. A similar plot was attempted for a number of coals shown also in figure 9. From the best straight line for the activated carbon, it is indicated that the carbon removed about 15 percent of its weight of COD from an initial COD of about 65 ppm to a residual of 20 ppm COD. These figures compare favorably with those reported in footnote 1, page 5.

The individual points for the coal isotherms are generally too scattered to have rational significance. A single straight line through the scattering of points would be almost vertical. By estimation, some of the better adsorbing coals plotted indicated COD removals of 2.5-4.5 percent of their weight. Possibly the adsorptive capacity of coal cannot be correlated by the isotherms because the system is complicated by factors such as:

1. There are chemical reactions involved instead of, or in addition to, physical adsorption.

2. There is COD contributed by the coals to complicate the system in that adsorption of some compounds and desorption of others are occurring simultaneously.

An attempt is made in figure 10 to compare a number of adsorption isotherms for COD on flyashes with those on activated carbon. The individual points for the flyashes are also too scattered to be connected with straight lines. To permit an estimation, the flyashes are grouped and represented by double boundary lines. These lines are parallel to the boundary lines representing activated carbon; in other words, the

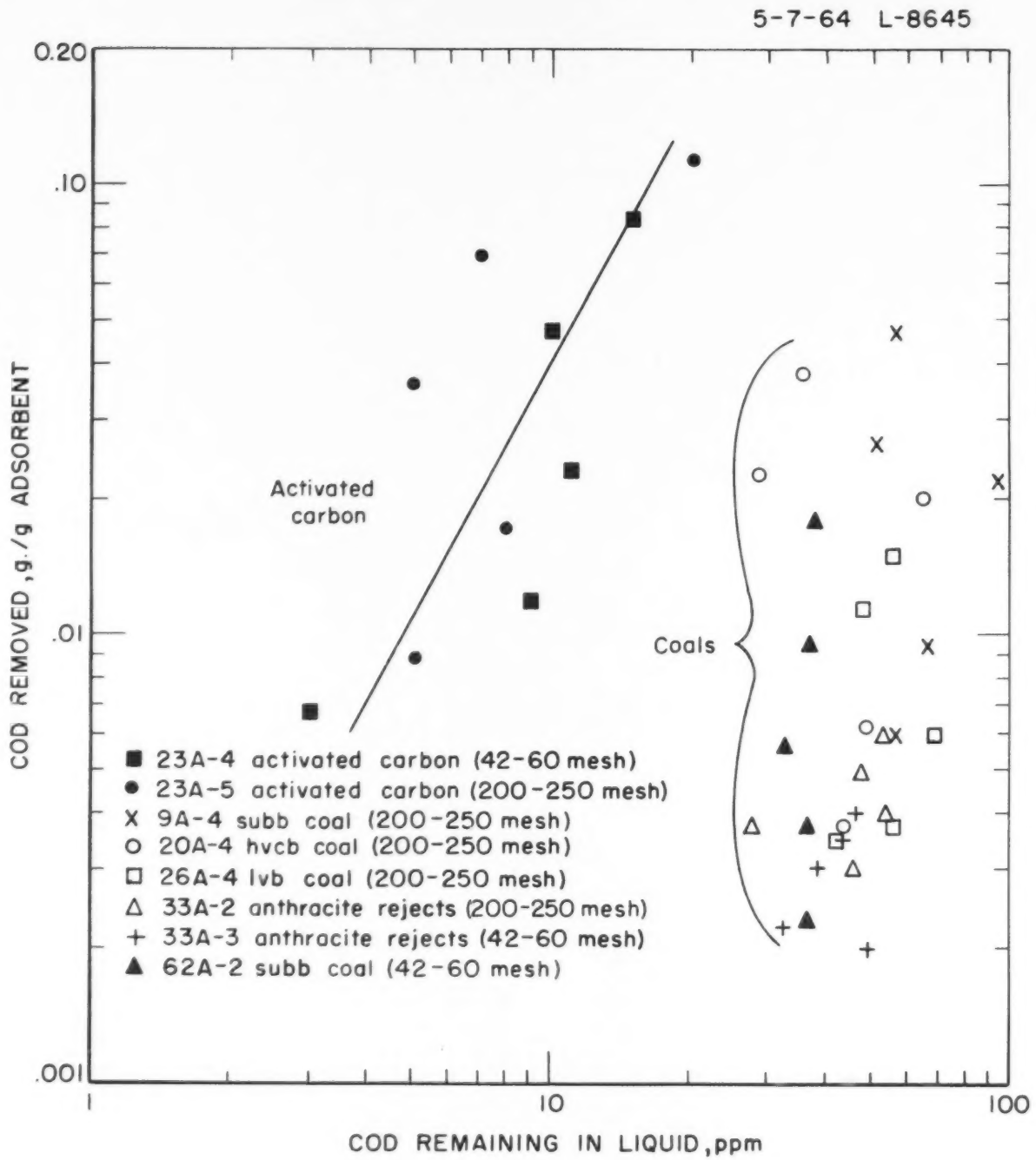



Figure 9. Adsorption Isotherms for COD on Activated Carbon and Various Coals.

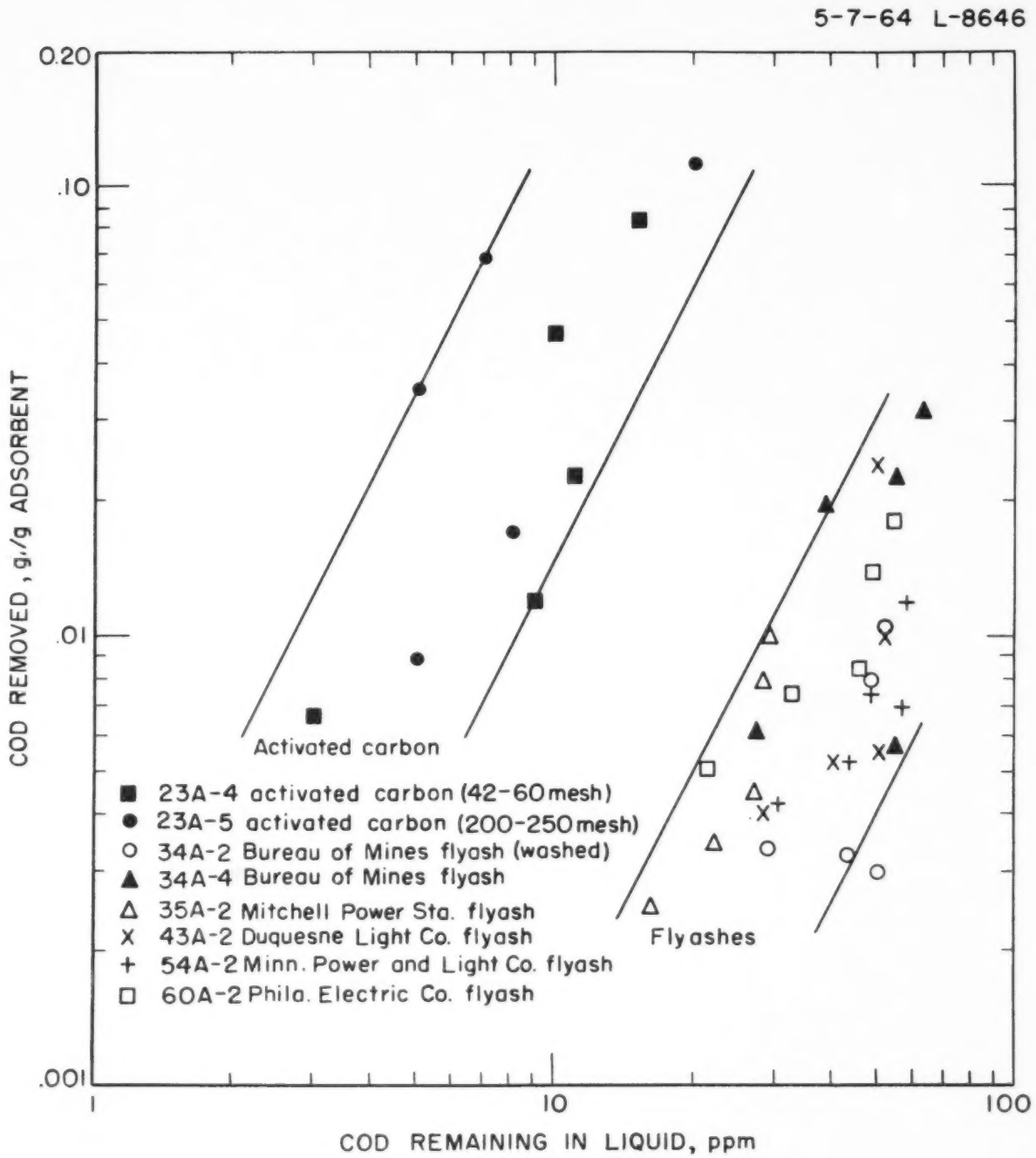



Figure 10. Adsorption Isotherms for COD on Activated Carbon and Flyashes.

slopes of the lines for carbon and flyash are similar; but, as with the coals, the adsorption capacity of activated carbon is much superior. The best flyashes could remove only about 3.5 percent of their weight of COD.

## Statistical Analyses of Data

Due to the general scattering of the data, replicate tests were made with several adsorbents in order to establish the variability of the data. Fifteen replicate tests were made with hvcb coal 20A, and 17 replicates each with flyash 60A and sub-bituminous B coal 9A. Statistical analyses of the COD removals obtained in these tests are presented in table 9. Standard deviations of 14.65, 6.47, and 3.95 percent were obtained with coal 20A, coal 9A, and flyash 60A, respectively, resulting in deviations of the mean of 33, 23, and 8 percent. The significantly lower variability obtained with the flyash is believed to be due to its finer particle sizes, resulting in more uniform samples. Also the flyash would be expected to be more uniform in, and contain fewer components since only noncumbustibles remain after the combustion process. In the case of the coal, however, the heterogeneity of coal generally would probably result in different variabilities for each coal if statistical evaluations were made of data from this type of batch test using small quantities of coal. However, in column tests or in large-scale tests where the waste water contacts a large volume of coal, the variability of the percent removal of contaminants would be expected to be very much reduced.

TABLE 9.- Statistical analyses of data from tests with hvcb coal (42-60 mesh), sub-bituminous B coal (42-60 mesh), and flyash (unsieved) stirred with secondary sewage in concentrations of 3 g/liter at 22° C for 24 hours

| Hvcb coal | | | | Sub-bituminous B coal | | | | Flyash | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Test No. | $X_i$ | $X_i-\bar{X}$ | $(X_i-\bar{X})^2$ | Test No. | $X_i$ | $X_i-X$ | $(X_i-\bar{X})^2$ | Test No. | $X_i$ | $X_i-\bar{X}$ | $(X_i-\bar{X})^2$ |
| | 52 | 7.7 | 59.3 | | 32 | 3.9 | 15.2 | | 56 | 6.7 | 44.9 |
| | 33 | -11.3 | 127.7 | | 29 | 0.9 | 0.8 | | 46 | - 3.3 | 10.9 |
| 20A-8 | 44 | - 0.3 | 0.1 | 9A-7 | 16 | -12.1 | 146.4 | 60A-4 | 41 | - 8.3 | 68.9 |
| | 65 | 20.7 | 428.5 | | 26 | - 2.1 | 4.4 | | 53 | 3.7 | 13.7 |
| | 48 | 3.7 | 13.7 | | 29 | 0.9 | 0.8 | | 46 | - 3.3 | 10.9 |
| | 51 | 6.7 | 44.9 | | 26 | - 2.1 | 4.4 | | 50 | 0.7 | 0.5 |
| | 21 | -23.3 | 542.9 | | 32 | 3.9 | 15.2 | | 46 | - 3.3 | 10.9 |
| 20A-9 | 21 | -23.3 | 542.9 | 9A-8 | 39 | 10.9 | 118.8 | 60A-5 | 50 | 0.7 | 0.5 |
| | 56 | 11.7 | 136.9 | | 42 | 13.9 | 193.2 | | 53 | 3.7 | 13.7 |
| | 56 | 11.7 | 136.9 | | 19 | - 9.1 | 82.8 | | 53 | 3.7 | 13.7 |
| | | | | | 29 | 0.9 | 0.8 | | 46 | - 3.3 | 10.9 |
| | 47 | 2.7 | 7.3 | | | | | | | | |
| | 64 | 19.7 | 388.1 | | 30 | 1.9 | 3.6 | | 50 | 0.7 | 0.5 |
| 20A-10 | 30 | -14.3 | 204.5 | | 30 | 1.9 | 3.6 | | 46 | - 3.3 | 10.9 |
| | 26 | -18.3 | 334.9 | 9A-9 | 23 | - 5.1 | 26.0 | 60A-6 | 50 | 0.7 | 0.5 |
| | 51 | 6.7 | 44.9 | | 23 | - 5.1 | 26.0 | | 53 | 3.7 | 13.7 |
| | 665 | | 3,013.5 | | 23 | - 5.1 | 26.0 | | 53 | 3.7 | 13.7 |
| | | | | | 30 | 1.9 | 3.6 | | 46 | - 3.3 | 10.9 |
| | | | | | 478 | | 671.6 | | 838 | | 249.7 |

$X_i$ = COD removal, pct

$\bar{X} = \frac{665}{15} = 44.3$

$S = \sqrt{\frac{3013.5}{14}} = \sqrt{215.25} =$ 14.65 pct std. dev.

$\frac{14.65}{44.3} =$ 33 pct deviation of mean

$X_i$ = COD removal, pct

$\bar{X} = \frac{478}{17} = 28.1$

$S = \sqrt{\frac{671.6}{16}} = \sqrt{41.98} =$ 6.47 pct std. dev.

$\frac{6.47}{28.1} =$ 23 pct deviation of mean

$X_i$ = COD removal, pct

$\bar{X} = \frac{838}{17} = 49.3$

$S = \sqrt{\frac{249.7}{16}} = \sqrt{15.61} =$ 3.95 pct std. dev.

$\frac{3.95}{49.3} =$ 8 pct deviation of mean

## ECONOMIC EVALUATION

To estimate the potential merit of utilizing coal as adsorbent, a preliminary cost estimate was made for treating the final effluent of a 100-million-gal/day secondary sewage treatment plant. Based on the repetitive tests, a 4 percent by weight pickup of COD was assumed along with an influent COD of 100 ppm and an effluent COD of 25 ppm. Fixed bed adsorption towers with downflow at a throughput of 6 gal/min/sq ft were arbitrarily chosen. A simplified process flowsheet which shows all the major materials handling equipment is shown in figure 11.

The overall investment cost for a 100 million gal/day plant amounted to $4,111,300, which is about 3-4 percent of the cost of the sewage treatment plant. The cost of treating, including drying of the coal for combustion, amounts to 1.98¢/1,000 gal, and with a 13 percent return on investment (20 percent total capital charges), 3.44¢/1,000 gal. The cost breakdown is shown in table 10. No charge was made for coal as it is assumed that the coal is consumed in a powerplant.

Figure 11. Simplified Flowsheet for the Treatment of Secondary Effluent with Coal.

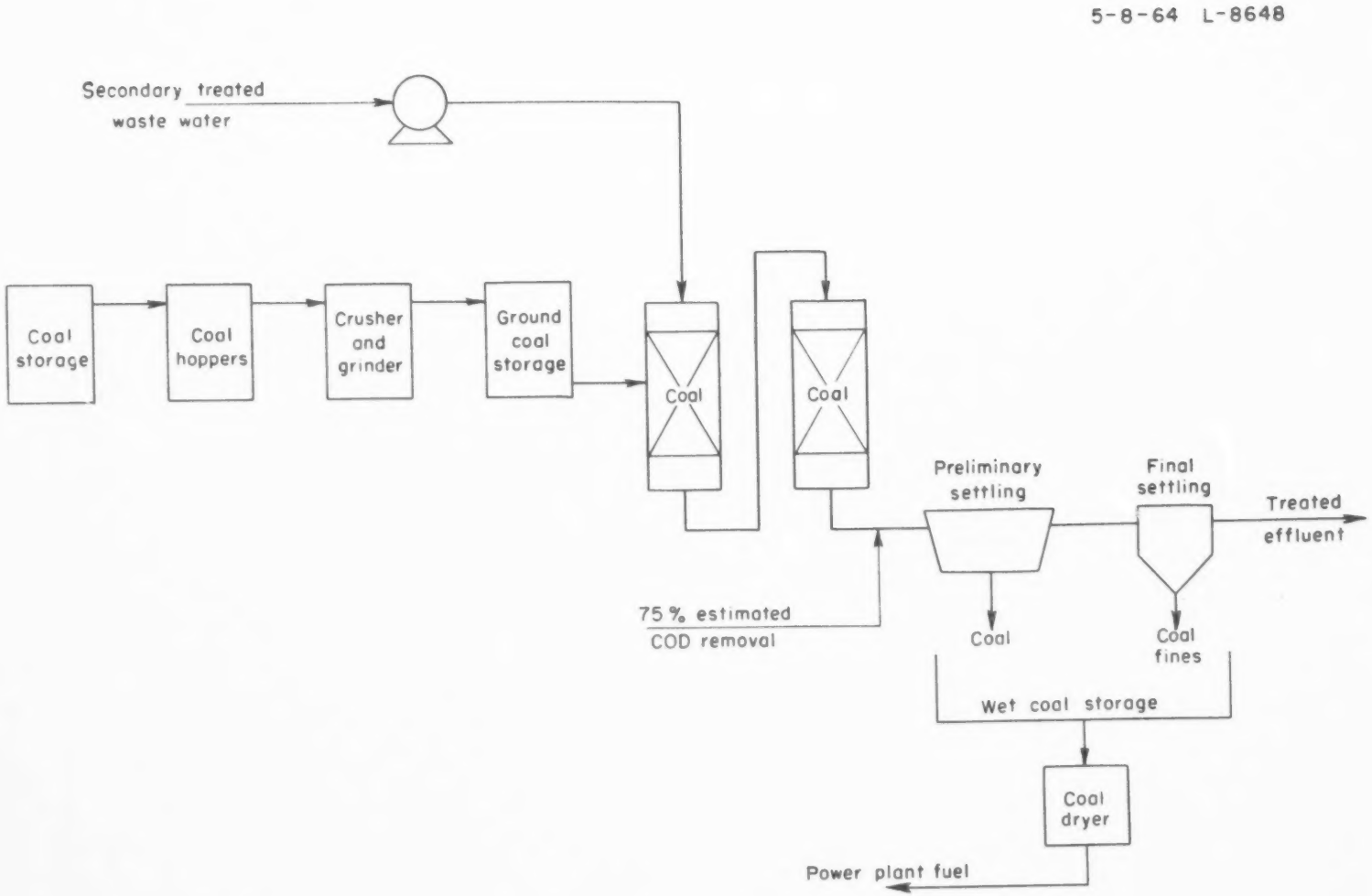


TABLE 10.- Estimated costs for treatment of 100,000,000 gal/day secondary sewage

| Capital Costs | Material | Labor | |
|---|---|---|---|
| **Major Equipment** | | | |
| | $ | $ | |
| 42 vessels (25'x25'x20') at $25,000 ea. | 1,050,000 | 105,000 | |
| 24 pumps (32 hp) at $2,500 ea. | 60,000 | 15,000 | |
| Coal handling, storage, preparation and drying | 251,000 | 29,500 | |
| Total | 1,361,000 | 149,500 | |
| **Other factors** | | | |
| Foundations, structures, instrumentation, piping, electrical, painting, and miscellaneous | 801,400 | 491,500 | |
| Total direct costs | | | $2,803,400 |
| Field indirect costs, engineering, overhead and administration, and 10 pct contingency | | | 1,009,600 |
| Total cost of erected plant | | | 3,813,000 |
| Operating capital including 30-day coal supply | | | 298,000 |
| Total Investment | | | $4,111,000 |

| Annual Operating Costs | |
|---|---|
| **Direct Costs** | |
| Raw materials, power and steam | $ 118,100 |
| Labor including 15% for supervision | 120,800 |
| Plant maintenance labor and material | 59,500 |
| Payroll overhead and operating supplies | 41,900 |
| Total Direct Costs | 340,300 |
| Indirect Costs | 96,100 |
| Fixed costs (insurance and depreciation, total of 7 pct of capital) | 287,800 |
| Total operating costs | $ 724,200 |

$$\text{Cost/M gal} = \frac{\$724,200}{3.65\times10^{7}\ \text{gal}} = 1.98¢/\text{M gal treated.}$$

With return on Investment:

| | |
|---|---|
| Direct Costs | $ 340,300 |
| Indirect Costs | 96,100 |
| 20 pct Capital charges | 820,200 |
| Total | $1,256,600 |

$$\frac{\text{Annual Cost}}{\text{Annual gallonage treated}} = \frac{\$1,256,000}{3.65\times10^{7}\ \text{M gal}} = 3.44¢/1{,}000\ \text{gal treated.}$$

## CONCLUSIONS

At lease one of each of the major ranks of coal in this country has been tested for its adsorptive capacity to remove COD from secondary waste water. Many of the coals and coal-derived materials possess some degree of adsorptive capacity for final waste contaminants. Because some coals contain constituents that contribute to the COD content during treatment, careful selection must be made in choosing a coal that will give satisfactory adsorption. Although the best coals are only about one-quarter as efficient for COD adsorption as activated carbon, use of coal has inherent advantages over use of other adsorbents. Coal costs about 0.25¢/lb while granular activated carbon sells for about 25¢/lb. The coal after use in waste water treatment can be burned along with the adsorbed wastes with no loss in fuel value. Burning of the coal also alleviates the problem of ultimate disposal of the removed wastes which is an unsolved problem of many such waste disposal schemes. The batch tests indicate that some of the more effective coals would have an adsorptive capacity to remove about 4 percent of the weight of the coal. A continuous type test with the waste water flowing through fixed beds of coal would give more meaningful results. From the results obtained in this investigation such a test is proposed at a waste treatment plant.

Treatment costs of 2 to 3.5¢/1,000 gallons of water treated compared favorably with the costs estimated for treating with activated carbon. It is believed that there is a place for coal as an adsorbent for final waste waters, if not in competition with activated carbon, at least as an adjunct to it.

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